CALIFORNIA ENERGY COMMISSION

Residential Duct Placement Field Test and Research Reports

Tests of Homes with Ducts in Conditioned Space (product 6.6.2b)

Literature Search (product 6.3.1)

Interview with Builders and Researchers (product 6.3.2)

Representative House Designs Summary Report (product 6.3.3)

TECHNICAL REPORT

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Prepared By:
GARD Analytics, Inc.
Roger Hedrick, Lead Author
Park Ridge, Illinois

Managed By:
New Buildings Institute
Cathy Higgins, ***Program Director***
White Salmon, Washington
CEC Contract No. 400-99-013

Prepared For:
Donald Aumann,
Contract Manager

Nancy Jenkins,
PIER Buildings Program Manager

Terry Surles,
PIER Program Director

Robert L. Therkelsen
Executive Director

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Project Director: Roger Hedrick, GARD Analytics, Inc.

Technical Assistance: Geof Syphers of XENERGY, Rob Hammon, Steve Vang and Bruce Baccei of ConSol, Bill Irvine of BCI Testing. Additional technical review by Alan Cowan of New Buildings Institute.

Review and Advisory Committee: Rick Chitwood of Chitwood Energy Management, Iain Walker of Lawrence Berkeley National Laboratory, Joe Lstiburek of Building Science Corporation, Bruce Wilcox of Berkeley Solar Group, Jamie Lyons of Energetics, Inc., Marshall Hunt of Pacific Gas & Electric.

Project Management: Cathy Higgins, Program Director for New Buildings Institute, and Don Aumann, Contract Manager for the California Energy Commission.

PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

This document is one of 33 technical attachments to the final report of a larger research effort called *Integrated Energy Systems: Productivity and Building Science Program* (Program) as part of the PIER Program funded by the California Energy Commission (Commission) and managed by the New Buildings Institute.

As the name suggests, it is not individual building components, equipment, or materials that optimize energy efficiency. Instead, energy efficiency is improved through the integrated design, construction, and operation of building systems. The *Integrated Energy Systems: Productivity and Building Science Program* research addressed six areas:

- Productivity and Interior Environments
- Integrated Design of Large Commercial HVAC Systems
- Integrated Design of Small Commercial HVAC Systems
- Integrated Design of Commercial Building Ceiling Systems
- Integrated Design of Residential Ducting & Air Flow Systems
- Outdoor Lighting Baseline Assessment

The Program's final report (Commission publication #P500-03-082) and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the *Integrated Energy Systems: Productivity and Building Science Program*. The final report and attachments are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This attachment, "Residential Duct Placement Field Test and Research Reports" (Attachment A-29) provides supplemental information to the program's final report within the **Integrated Design of Residential Ducting & Air Flow Systems** research area. It includes the following reports:

1. **Tests of Homes with Ducts in Conditioned Space.** This report describes testing conducted of California homes built with ducts in conditioned space. This testing was the first step in the process of estimating the energy, energy demand and energy cost savings that can be expected for houses built with ducts in conditioned space.

2. **Literature Search.** This provides a summary of the literature review conducted to identify previous work on ducts in conditioned space, and to guide the efforts of this project.

3. **Interview with Builders and Researchers.** This report describes the results of interviews conducted with builders and researchers involved in building homes with ducts in conditioned space.

4. **Representative House Designs Summary Report.** This describes the home designs that were selected to represent typical houses currently being built in California. These house designs were

subsequently used as the basis for cost estimates and energy and energy cost savings estimates for modifying the construction to include ducts inside conditioned space.

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced these documents as part of a multi-project programmatic contract (#400-99-413). The Buildings Program includes new and existing buildings in both the residential and the non-residential sectors. The program seeks to decrease building energy use through research that will develop or improve energy efficient technologies, strategies, tools, and building performance evaluation methods.

For other reports produced within this contract or to obtain more information on the PIER Program, please visit www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200. All reports, guidelines and attachments are also publicly available at www.newbuildings.org/pier.

ABSTRACT

The "Residential Duct Placement Field Test and Research Reports" attachment is a set of four reports produced as a part of the Integrated Design of Residential Ducting & Air Flow Systems project. This was one of six research projects within the *Integrated Energy Systems: Productivity and Building Science* Program, funded by the California Energy Commission's Public Interest Energy Research (PIER) Program.

Poorly performing residential duct systems installed in unconditioned space can have a significant effect on energy use and comfort. This research project developed realistic alternatives that would bring the ductwork within the conditioned building envelope. This attachment contains research reports, field test data and other information that informed the development of these construction alternatives. Specifically, it contains:

- **Tests of Homes with Ducts in Conditioned Space.** A report describing the testing of California homes built with ducts in conditioned space.
- **Literature Search.** A summary of the literature review conducted to identify previous research on ducts in conditioned space.
- **Interview with Builders and Researchers.** A report describing results of interviews conducted with builders and researchers involved in building homes with ducts in conditioned space.
- **Representative House Designs Summary Report.** A report describing the home designs selected to represent typical houses currently being built in California. These designs were subsequently used as the basis for cost estimates and energy and energy cost savings estimates for modifying the construction to include ducts inside conditioned space.

Author: Roger Hedrick, GARD Analytics, Inc.

Key words: home building, duct, conditioned space, unconditioned space, air handler, attic, energy saving, electricity saving, air leak, infiltration, energy efficient home

Tests of Homes with Ducts in Conditioned Space

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Integrated Energy Systems
Productivity and Building Science

On behalf of the:
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Integrated Design of Residential Ducting and Airflow Systems
Roger Hedrick

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This report is a part of the *Integrated Energy Systems — Productivity and Building Science* project, a Public Interest Energy Research (PIER) program. It is funded by California ratepayers through California's System Benefit Charges administered by the California Energy Commission under (PIER) contract No. 400-99-013, and managed by the New Buildings Institute.

Project Director: Roger Hedrick, GARD Analytics, Inc.

Technical Assistance: Geof Syphers, XENERGY; Rob Hammon, ConSol; Bill Irvine, BCI Testing.

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Project Management: Cathy Higgins, Program Director for the New Buildings Institute and Don Aumann, Contract Manager for the California Energy Commission.

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ABOUT PIER

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission, annually awards up to $62 million to conduct the most promising public interest energy research by partnering with research, development and demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

1. Buildings End-use Energy Efficiency
2. Industrial/Agricultural/Water End-use Energy Efficiency
3. Renewable Energy
4. Environmentally Preferred Advanced Generation
5. Energy-Related Environmental Research
6. Strategic Energy Research.

This project contributes to #1 above, the PIER Buildings Program Area. For more information on the PIER Program, please visit the Commission's Web site at: www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200. For other public reports within the *Integrated Energy Systems — Productivity and Building Science* project, please visit www.newbuildings.org/PIER

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OBJECTIVES

This report describes the testing of homes in California that have been built with ducts in conditioned space. This testing is the first step in the process which will result in estimates of energy, energy demand and energy cost savings which can be expected for houses built with ducts in conditioned space. This report describes the houses tested, the testing performed and the data collected. Analysis of the data will be described in a subsequent report, as will analyses aimed at predicting savings.

Previous reports have described techniques used to build houses with ducts in conditioned space and focused on changes to standard practice for designers, builders, and the various subcontractors. Other reports will be prepared under this element of the PIER program that will describe market barriers and strategies to overcome them, and cost estimates for building ducts in conditioned space. A final guideline document will combine the information from these four reports that is relevant to the builder/contractor audience into a single package.

INTRODUCTION

New houses in California typically are built with the air handler and ductwork located in the unconditioned attic. The ductwork is commonly built with ductboard plenums and flex duct, insulated to R4.2, or sometimes R6 (code requirement is R4.2). In recent years, numerous studies have found large energy losses from these systems, primarily due to air leaks in the air handler and duct system, but also including heat conducted through the duct material. These losses are especially deleterious in the summer when solar radiation can elevate the attic temperature well above the outdoor air temperature. Previous studies have found that typical duct systems can lose as much as 40% of the space conditioning energy consumed by the HVAC system.

Air leaks on the supply side of the system are lost to the unconditioned attic and eventually to the outdoors, while leaks on the return side result in unconditioned air being brought into the system, increasing the space conditioning load. Unbalanced leakage (for example, large supply leaks with small return leaks) can significantly affect the air pressure in the house resulting in increased infiltration and the corresponding increase in space conditioning loads. Leakage can also cause comfort problems by reducing supply air flow to the house or to individual rooms, and by increasing infiltration.

The problem of duct leakage has primarily been addressed through a variety of programs aimed at reducing leakage in the duct system. These include several utility company programs which provided training to duct installers followed by duct leakage testing. The Title 24 ACM manual now includes a credit for ducts with tested leakage below 6% of system airflow. These programs have reduced typical duct leakage in new construction, but few builders take advantage of the Title 24 energy credit. It is believed that typical duct leakage values are now around 20% to 25% of system airflow. And, ducts are still located in the unconditioned attic where the leaks and thermal conduction is lost to the outdoors.

OVERVIEW

Placing ducts in conditioned space involves modifying the design and construction of the house such that the duct system is located inside both the air barrier and the thermal barrier. Different approaches are used to make this change, and each has advantages and disadvantages. Each approach, however, is used to find the best compromise between maximizing marketable floor area, minimizing energy cost, and minimizing construction cost impacts, while keeping the construction process as simple as possible.

In order to optimize the house design choices, information on the savings that can be expected with each approach is needed. Savings can be energy or demand savings. In order to determine the savings that can be expected, a number of houses built in California with ducts in conditioned space were tested. This report describes that testing. It includes general descriptions of the houses tested, the test procedures used, and the data collected.

THREE APPROACHES

Three approaches to building ducts in conditioned space have been developed and applied to actual houses. These three are: Dropped Ceiling, Cathedralized Attic, and Plenum Truss.

The **Dropped Ceiling** approach is applied to houses with high ceilings, 9' to 10'. In hallways and other ancillary spaces, a dropped ceiling is installed at 8' high, with the ducts installed in the space between. By providing an air barrier at the 9' or 10' ceiling height, the duct space is brought into conditioned space. Supply registers are located on interior walls, adjacent to the dropped ceiling.

The **Cathedralized Attic** approach is applied to houses with conventional pitched attics. The roof deck is air sealed to provide the primary air barrier, i.e., ridge and soffit vents are not used. The ceiling insulation is moved to the roof level, and installed immediately below the roof deck. With the air and thermal barriers moved to the roof, the attic is brought into conditioned space. The HVAC system is then installed in the attic as it normally is. The houses that have been built with this approach have generally used interior register locations.

The **Plenum Truss** approach is also applied to houses with conventional attics. A modified scissors truss is used to provide a space between the ceiling and the bottom chord of the trusses. Sheet material, such as fiberboard, is installed on the bottom chord of the trusses, and sealed to provide the air barrier. Insulation is then installed above. The space between the bottom chord of the trusses and the ceiling is then inside conditioned space, and used for HVAC system installation. The conditioned duct space may not extend to the full width of the attic, so again interior supply register locations are used.

Interior register locations have been used for most houses built to date with the three approaches discussed in this report. In the past, being near exterior walls was less comfortable than elsewhere in the house. This was due to poor wall insulation and windows with poor U-values allowing the wall surface temperatures to be cold (or hot). This caused the radiant temperature to be lower (or higher) than the desired space temperature, as well as drafts caused by convective heat transfer. Additionally, windows were sometimes leaky, allowing additional drafts. Locating supply registers near exterior walls allowed the supply air to wash over the exterior wall, bringing the surface temperature closer to the space temperature, and breaking up drafts. Current California housing, however, has better insulation, lower air leakage, and better windows. Together, these improvements minimize the discomfort effects described above. As a result, the need for exterior supply registers disappears. This allows the use of interior register locations, which provide benefits to the builder through reduced duct material (the duct runs are shorter), and energy benefits because there is less duct surface area, minimizing thermal conduction. With the interior register locations, however, it is desirable to use higher quality registers that will provide better mixing in the space.

Descriptions of the Tested Houses

There were a total of 16 houses tested. Of these, 12 used the Cathedralized Attic approach, and four used the Dropped Ceiling approach. There were no houses identified which used a Plenum Truss approach.

Of the houses with Cathedralized attics, 9 were built by Pulte Homes at their Sun Lakes development in Banning, California. Current construction at this development is made up entirely of three house models, although only two were currently being built and were tested. The other three houses were built by three different builders, and are located in Livermore, El Dorado Hills, and Redding, California.

The four Dropped Ceiling homes were all built with Chitwood Energy Management serving as both the HVAC and the insulation subcontractor. They are all located in North Central California, in Mt. Shasta or Cottonwood. The Table below summarizes the houses tested.

House ID	Approach	# Similar	Gross Area	Bedrooms
Banning A	Cathedralized Attic	8	1675	2
Banning B	Cathedralized Attic	1	2139	2/3
Cottonwood	Dropped Ceiling	1	3150	2/3
El Dorado Hills	Cathedralized Attic	1	2873	3/4
Livermore	Cathedralized Attic	1	2650	3/4
Mt. Shasta A	Dropped Ceiling	1	1600	3
Mt. Shasta B	Dropped Ceiling	1	1485	2/3
Mt. Shasta C	Dropped Ceiling	1	1550	3
Redding	Cathedralized Attic	1	2500	2/3

Note: 2/3 or 3/4 bedrooms indicates 2 (or 3) bedrooms plus a den.

Testing Performed

The testing conducted at the test sites consisted of four primary test procedures:

- duct leakage,
- duct leakage to outdoors,

- the Delta-Q test of duct leakage, and
- measurement of temperature change of supply air as it passes through the ducts.

In some houses, the duct leakage and duct leakage to outside were measured with the attic hatch both open and closed. In addition, with the system operating, static pressures were measured in selected rooms, and between the supply and return plenums and the duct space (dropped ceiling or attic). The house was inspected, room measurements of area and volume were taken, and photographs were taken of interesting features.

The duct leakage was measured by sealing all the supply registers, and pressurizing the duct system to 25 Pa with a duct blaster. The flow rate through the duct blaster required to maintain 25 Pa is the duct leakage at 25 Pa. The duct leakage to outside is measured by performing the duct leakage test, but with the house pressurized to 25 Pa using a blower door. Since the pressures in the house and the duct system are the same, there is no flow between them and the duct blaster flow in now only that portion of the duct leakage which is escaping to the outdoors.

The Delta-Q test involves performing a series of blower door tests over a range of pressures, both pressurizing and depressurizing, with the air handling system both on and off. The data can then be used to derive supply and return duct leakage under normal operating conditions.

Thermocouples were inserted into the supply plenum and into supply registers. Temperatures were logged over a 20 to 30 minute period of system operation. Temperatures in the duct space and outdoors were also recorded. These data will be used to investigate conductive thermal losses.

In some houses the duct leakage measurements were made with the attic hatches open and closed. A key parameter for effectiveness of constructing ducts in conditioned space is the fraction of duct leakage which goes to outside. Theoretically, this is directly related to the ratio of the flow resistance of the air barrier between the ducts and the outdoors and the resistance of the air barrier between the ducts and indoors. If there were no resistance between the ducts and the indoors, as when exposed ductwork is used in commercial buildings, then duct leakage to the outdoors should be zero. Because of this, we wondered if leaving the attic hatch open, decreasing the flow resistance between the ducts and the indoors, would decrease the duct leakage to the outdoors.

One problem that can occur as a result of duct leakage is differential pressurization between rooms. Insufficient return air pathways between rooms and the central system return can also result in high room pressures. If differential pressures between a room and the outdoors are high, air exchange with the outdoors will increase. Differential pressurization can also reduce comfort by affecting supply air flows to different rooms. Pressures in selected rooms were measured with the system on to check for any extreme values.

Summary of Test Data

The table below summarizes the results of the duct leakage tests, including total duct leakage and leakage to the outside, with the attic hatch closed. The fraction of total duct leakage which goes to outside is also shown.

House ID	Type	Duct Leakage[1] (cfm @ 25 Pa)	Leak to Outside[1] (cfm @ 25Pa)	(%)
Banning A-2	Cathedralized Attic	42	15	36%
Banning A-3	Cathedralized Attic	28	17	61%
Banning A-4	Cathedralized Attic	52	38	73%
Banning B	Cathedralized Attic	49	30	61%
Banning A-5	Cathedralized Attic	41	29	71%
Banning A-6	Cathedralized Attic	47	22	47%
Banning A-7	Cathedralized Attic	49	40	82%
Banning A-8	Cathedralized Attic	46	27	59%
Banning A-9	Cathedralized Attic	48	21	44%
Cottonwood	Dropped Ceiling	41	6	15%
El Dorado Hills	Cathedralized Attic	91	70	77%
Livermore	Cathedralized Attic	50	32	64%
Mt. Shasta A	Dropped Ceiling	76	30	39%
Mt. Shasta B	Dropped Ceiling	68	22	32%
Mt. Shasta C	Dropped Ceiling	55	25	45%
Redding	Cathedralized Attic	68	44	65%
	Average[2]	**52**	**29**	**55%**
	Minimum[2]	**28**	**6**	**15%**
	Maximum[2]	**91**	**70**	**82%**

[1] Duct leakage includes both supply and return sides of the system.
[2] The three Average (and Minimum and Maximum) values may represent different houses.

Data were collected from four houses for duct leakage and duct leakage to the outside with the attic hatch open. The table below shows these values.

		Duct Leakage (cfm @ 25 Pa)		Leak to Outside (cfm @ 25 Pa)	
House ID	**Type**	**Closed**	**Open**	**Closed**	**Open**
El Dorado Hills	Cathedralized Attic	91	94	70	70
Livermore	Cathedralized Attic	50	50	32	31
Mt. Shasta B	Dropped Ceiling	68	71	22	22
Mt. Shasta C	Dropped Ceiling	55	56	25	24

The table shows that the hatch status made little difference in the leakage values. Opening the attic hatch increased duct leakage slightly in most cases, and decreased leakage to the outside in two cases. The changes, however, are too small to be considered significant.

Appendix 1

Delta Q Test Data

This appendix presents the data collected from the performance of the Delta Q test for duct leakage. An automated pressure test (APT) system is used to control the blower door fan to maintain a series of pressures at 10 Pa increments, ranging from 0 to 70 Pa, or up to the pressure that the blower door can maintain. This is done with the house both pressurized and depressurized. The test is repeated with the airhandling unit both on and off. The APT system records the airflow required to maintain each pressure.

This data was curve-fit to determine the leakage characteristics of the supply and return duct systems. The curve-fitting process, however, gave in poor results. Of the 15 houses with test data:

- three had curve-fit r^2 values (a measure of the quality of the fitted line) less than 0.25;
- five had a negative leakage on either the supply side, the return side, or both; and
- four had both negative leakage and low r^2 values.

Only three houses had apparently good results, but the problems with the other houses makes it difficult to have confidence in them. Later discussion with an experienced user of the DeltaQ test revealed that such results are not uncommon, particularly when the ducts have low leakage. When the leakage values are low, they approach the magnitude of the uncertainties in the calculation procedure, and cause the effects seen.

Banning A-2

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	na
-50	1051	1000
-45	976	937
-40	871	848
-35	796	784
-30	715	695
-25	625	603
-20	530	509
-15	434	352
0	0	0
15	422	397
20	508	491
25	594	589
30	699	681
35	797	738
40	870	855
45	927	923
50	1008	987
55	na	na
60	na	na
65	na	na
70	na	na

Banning A-3

Test attempted manually, unable to complete satisfactorily.

Banning A-4

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	na
-50	973	1010
-45	918	935
-40	861	869
-35	776	769
-30	700	704
-25	606	584
-20	520	540
-15	432	453
0	0	0
15	430	436
20	521	493
25	596	581
30	700	715
35	789	818
40	852	895
45	921	915
50	980	963
55	na	na
60	na	na
65	na	na
70	na	na

Banning B

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	na
-50	1117	1175
-45	1045	1116
-40	1018	1043
-35	916	969
-30	781	841
-25	725	765
-20	638	676
-15	542	530
0	0	0
15	523	534
20	581	579
25	718	748
30	794	829
35	912	904
40	994	999
45	1058	1097
50	1138	1137
55	na	na
60	na	na
65	na	na
70	na	na

Banning A-5

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	na
-50	1034	972
-45	940	911
-40	937	857
-35	855	787
-30	735	683
-25	614	629
-20	563	536
-15	454	429
0	0	0
15	474	444
20	584	500
25	671	623
30	745	715
35	847	764
40	915	868
45	927	939
50	1014	985
55	na	na
60	na	na
65	na	na
70	na	na

Banning A-6

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	na
-50	1179	1171
-45	1117	1077
-40	997	1040
-35	921	944
-30	836	822
-25	697	718
-20	596	626
-15	496	499
0	0	0
15	477	519
20	622	610
25	703	730
30	797	831
35	927	934
40	1046	1010
45	1067	1121
50	1171	1184
55	na	na
60	na	na
65	na	na
70	na	na

Banning A-7

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	na
-50	1281	1210
-45	1220	1173
-40	1132	1069
-35	1064	995
-30	936	945
-25	857	822
-20	761	703
-15	640	578
0	0	0
15	649	536
20	720	640
25	832	789
30	935	860
35	1065	1025
40	1139	1113
45	1199	1173
50	1280	1213
55	na	na
60	na	na
65	na	na

Banning A-8

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	na
-50	1020	983
-45	980	931
-40	922	846
-35	794	777
-30	728	674
-25	663	594
-20	567	521
-15	477	414
0	0	0
15	454	423
20	564	501
25	615	612
30	757	690
35	803	755
40	874	830
45	989	912
50	1006	977
55	na	na
60	na	na
65	na	na
70	na	na

Banning A-9

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	na
-50	1145	1125
-45	1088	1042
-40	1007	952
-35	906	876
-30	814	781
-25	715	690
-20	612	579
-15	511	482
0	0	0
15	515	426
20	615	588
25	727	633
30	830	757
35	933	899
40	1027	972
45	1094	1073
50	1167	1087
55	na	na
60	na	na
65	na	na
70	na	na

Cottonwood

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	1166
-55	na	1122
-50	1065	1038
-45	978	964
-40	864	886
-35	800	843
-30	796	777
-25	692	672
-20	573	580
-15	470	454
0	0	0
15	355	359
20	465	464
25	547	534
30	636	621
35	714	668
40	768	707
45	790	762
50	866	819
55	812	891
60	952	927
65	na	972
70	na	Na

El Dorado Hills

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	1550	1560
-50	1449	1472
-45	1369	1394
-40	1278	1264
-35	1216	1243
-30	1139	1094
-25	974	1004
-20	844	854
-15	760	738
0	0	0
15	733	767
20	800	788
25	867	906
30	988	1022
35	1049	1071
40	1144	1177
45	1261	1232
50	1305	1315
55	1417	1572
60	na	na
65	na	na
70	na	na

Livermore

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	na
-50	1089	1056
-45	1007	1026
-40	948	933
-35	914	911
-30	868	837
-25	732	754
-20	637	642
-15	560	581
0	0	0
15	526	517
20	589	592
25	630	659
30.4	722	768
35	788	837
39.1	859	884
45	967	956
50	980	993
55	na	na
60	na	na
65	na	na
70	na	na

Mt. Shasta A

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	na
-50	1162	1206
-45	1122	1184
-40	1050	1106
-35	1001	1064
-30	899	964
-25	804	860
-20	691	731
-15	579	632
0	0	0
15	564	589
20	653	683
25	732	760
30	821	864
35	898	925
40	979	1008
45	1085	1046
50	1111	1110
55	na	na
60	na	na
65	na	na
70	na	na

Mt. Shasta B

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	1803
-50	1640	1665
-45	1548	1573
-40	1464	1430
-35	1376	1385
-30	1307	1288
-25	1103	1086
-20	913	966
-15	na	762
0	0	0
15	744	706
20	863	849
25	967	980
30	1192	1109
35	1262	1185
40	1363	1288
45	1425	1363
50	1476	1412
55	1541	1530
60	na	na
65	na	na
70	na	na

Mt. Shasta C

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	na
-50	1361	1382
-45	1285	1329
-40	1200	1187
-35	1142	1167
-30	1085	1089
-25	915	943
-20	758	802
-15	650	693
0	0	0
15	618	646
20	716	740
25	803	813
30	928	960
35	985	1006
40	1074	1105
45	1209	1157
50	1225	1235
55	na	na
60	na	na
65	na	na
70	na	na

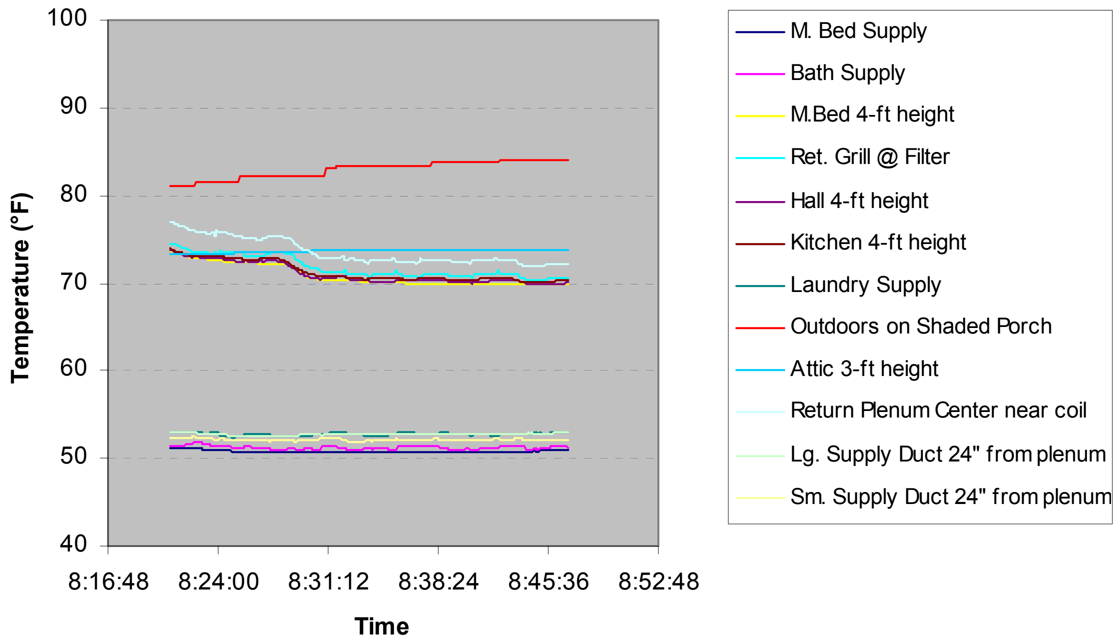
Redding

Pa	CFM Test 1	CFM Test 2
-70	na	na
-65	na	na
-60	na	na
-55	na	1715
-50	1502	1584
-45	1413	1496
-40	1393	1297
-35	1151	1317
-30	1243	1225
-25	1017	1033
-20	868	919
-15	763	725
0	0	0
15	708	672
20	656	808
25	920	932
30	1159	1075
35	1163	1150
40	1328	1172
45	1383	1296
50	1404	1343
55	na	1455
60	na	na
65	na	na
70	na	na

Appendix 2

Temperature Test Data Plots

Banning A-2



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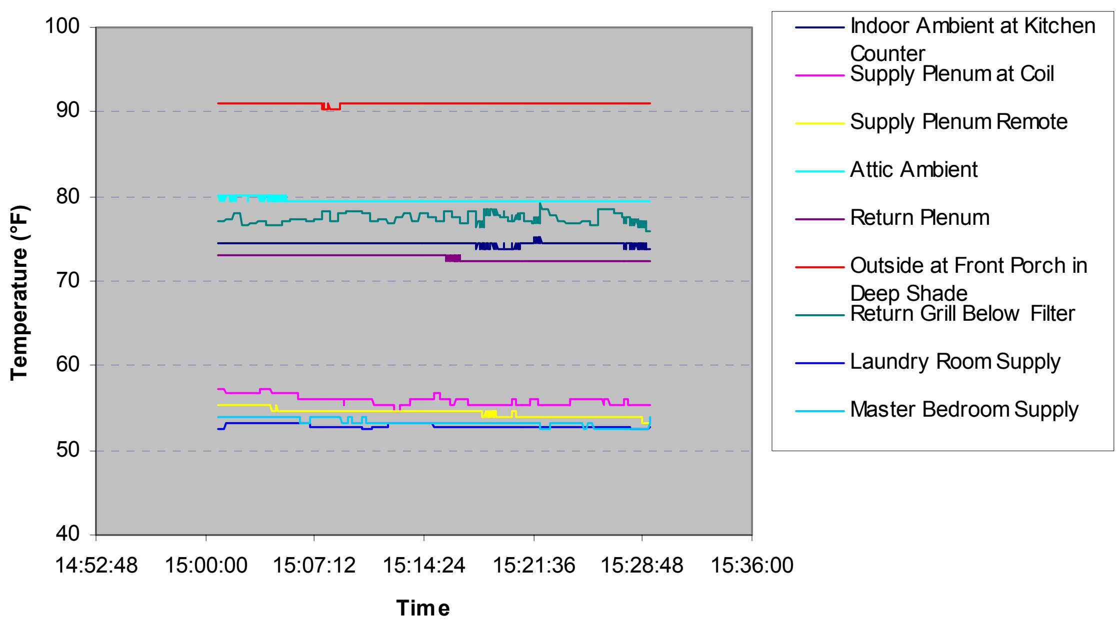
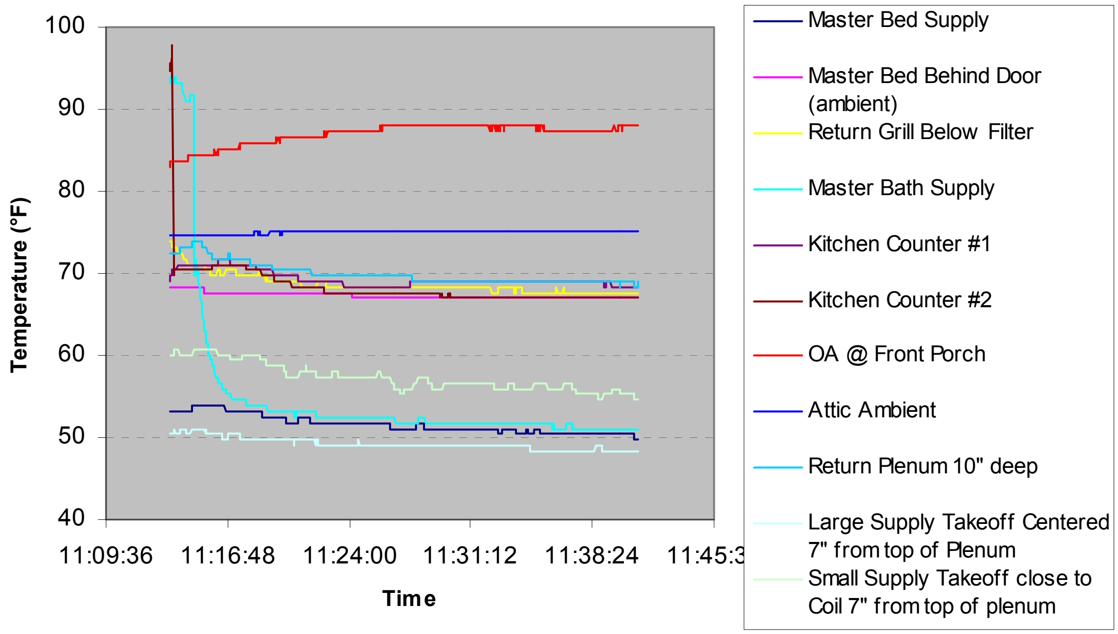


Banning A-3 – Test 1



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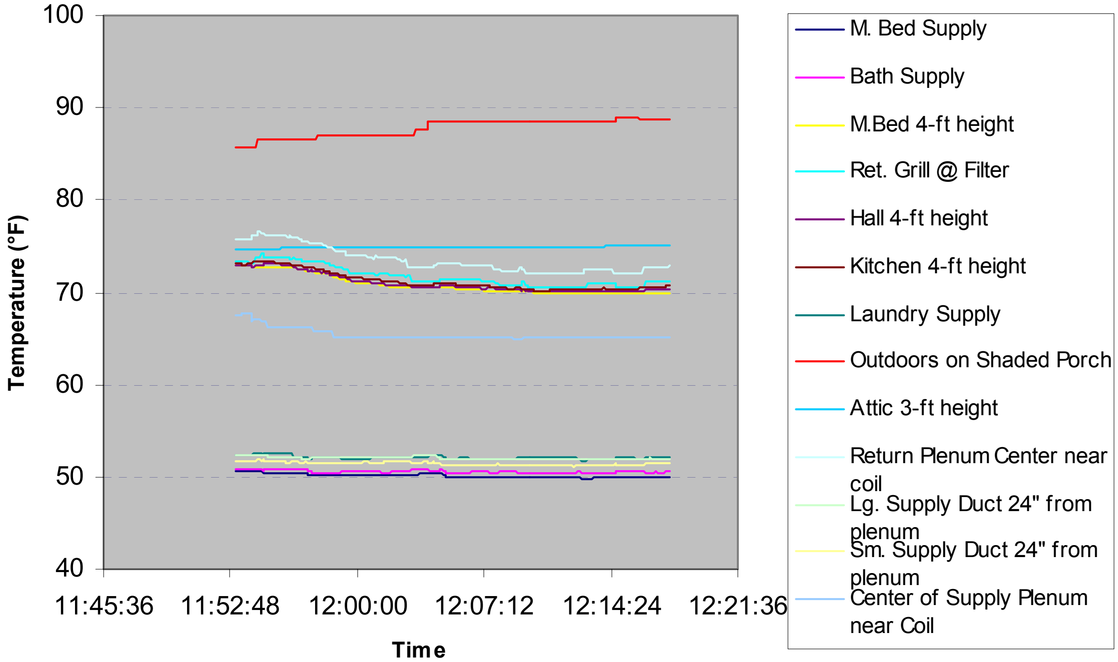
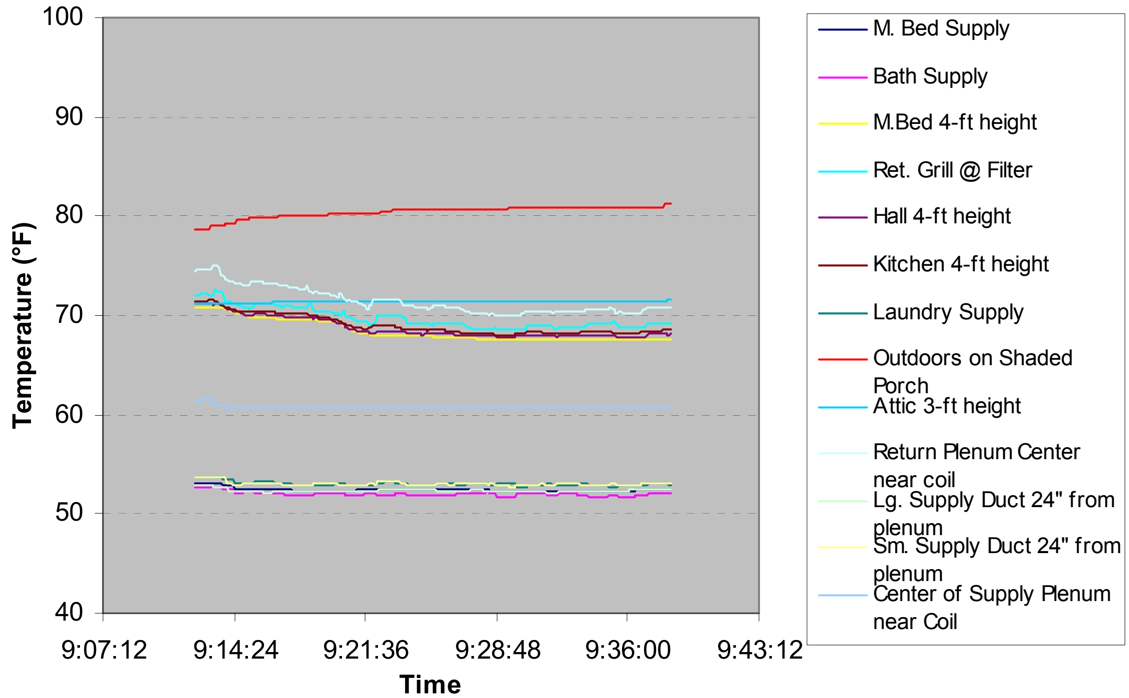


Banning B

Temperature data was not collected at this site.

Banning A-5



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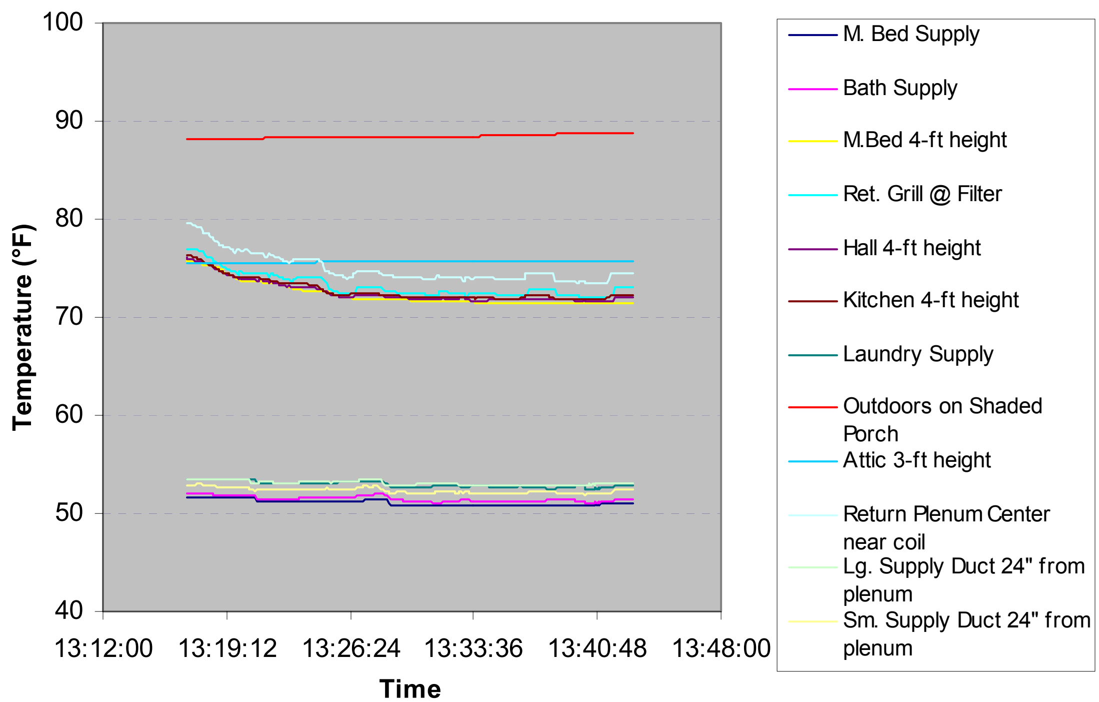

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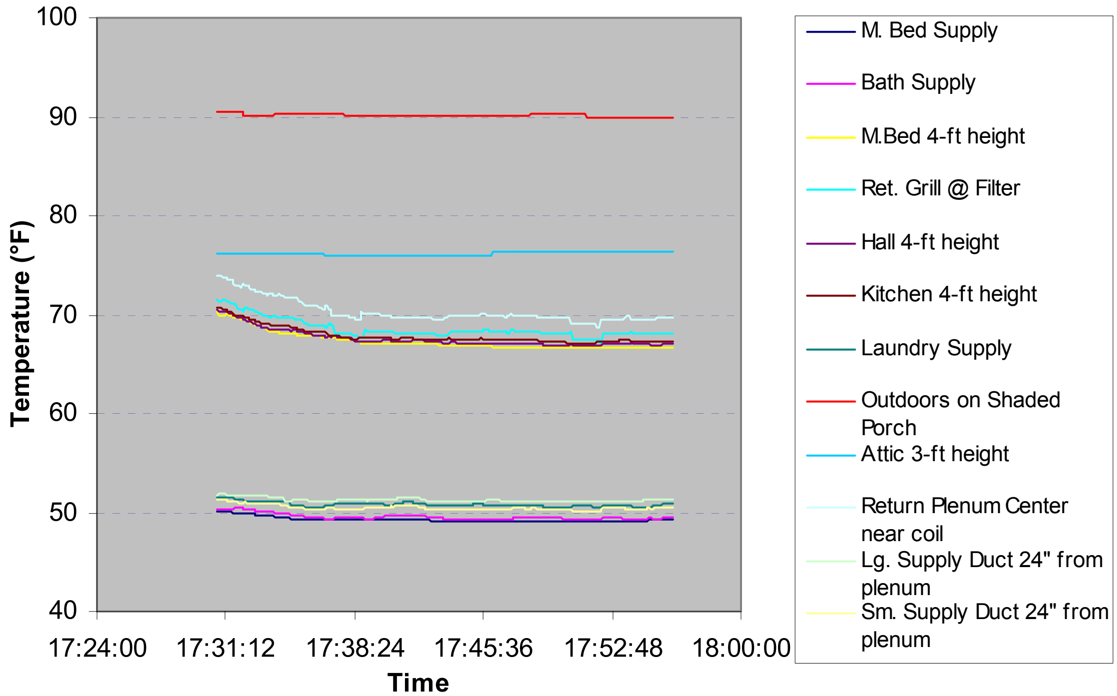

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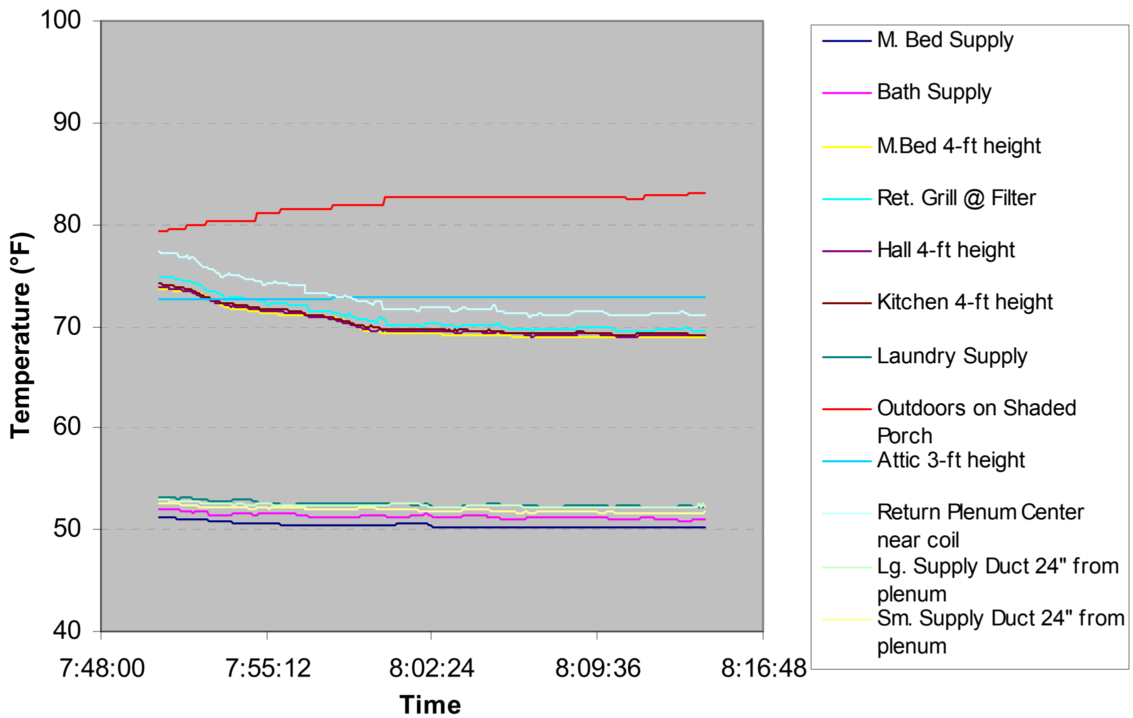

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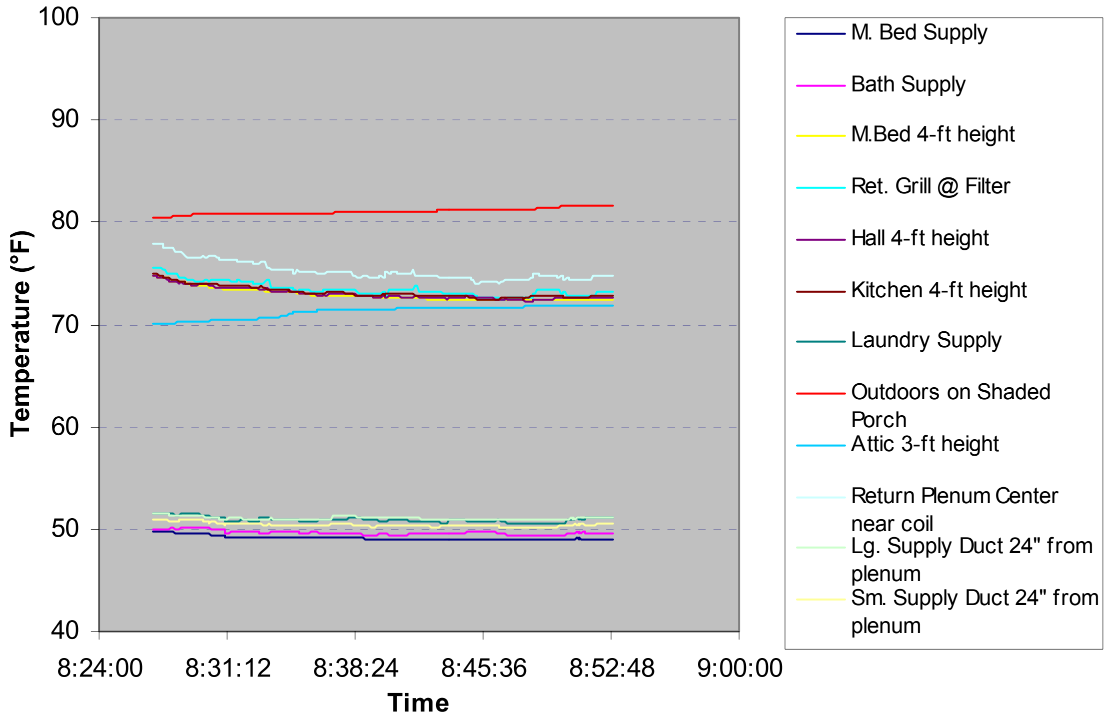
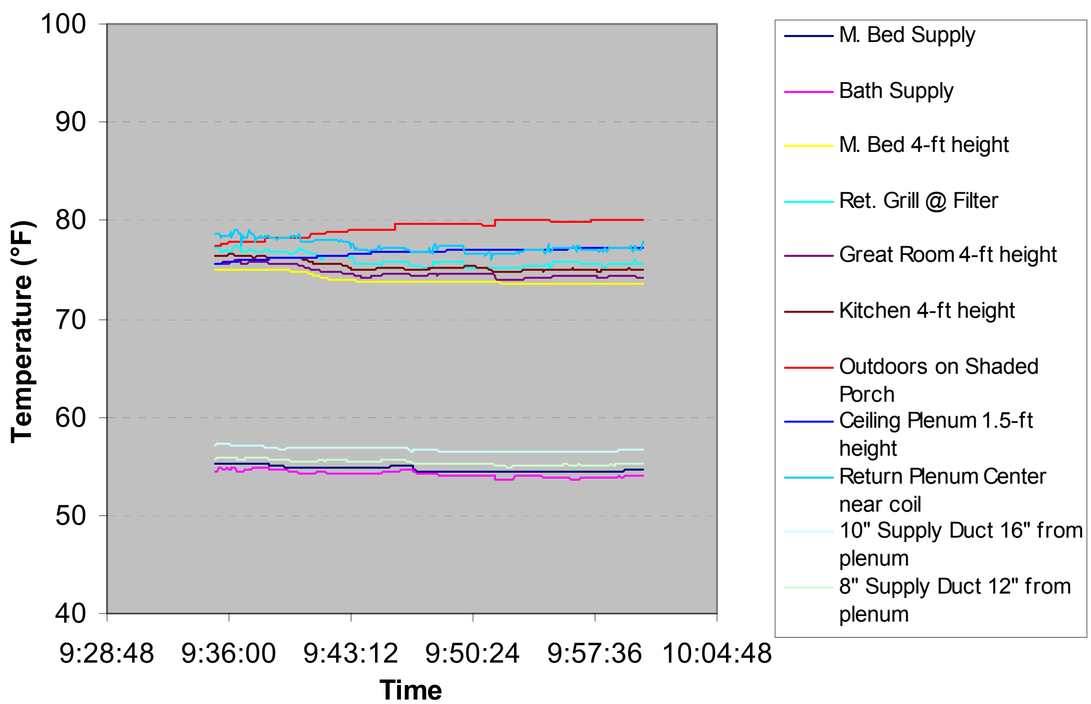


Cottonwood



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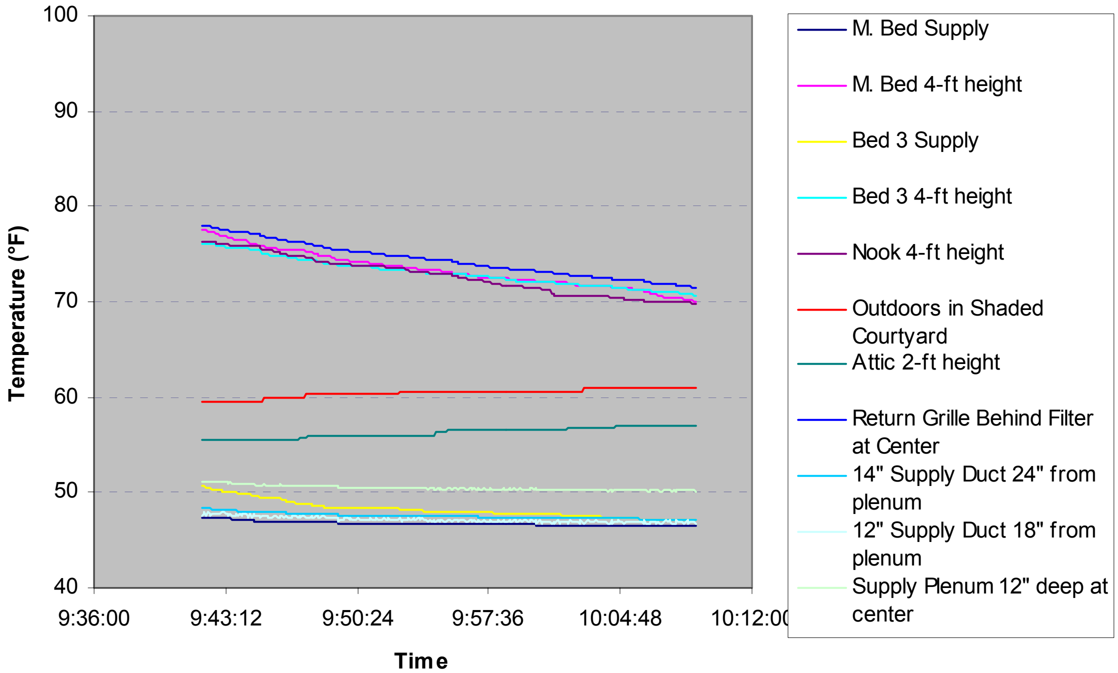

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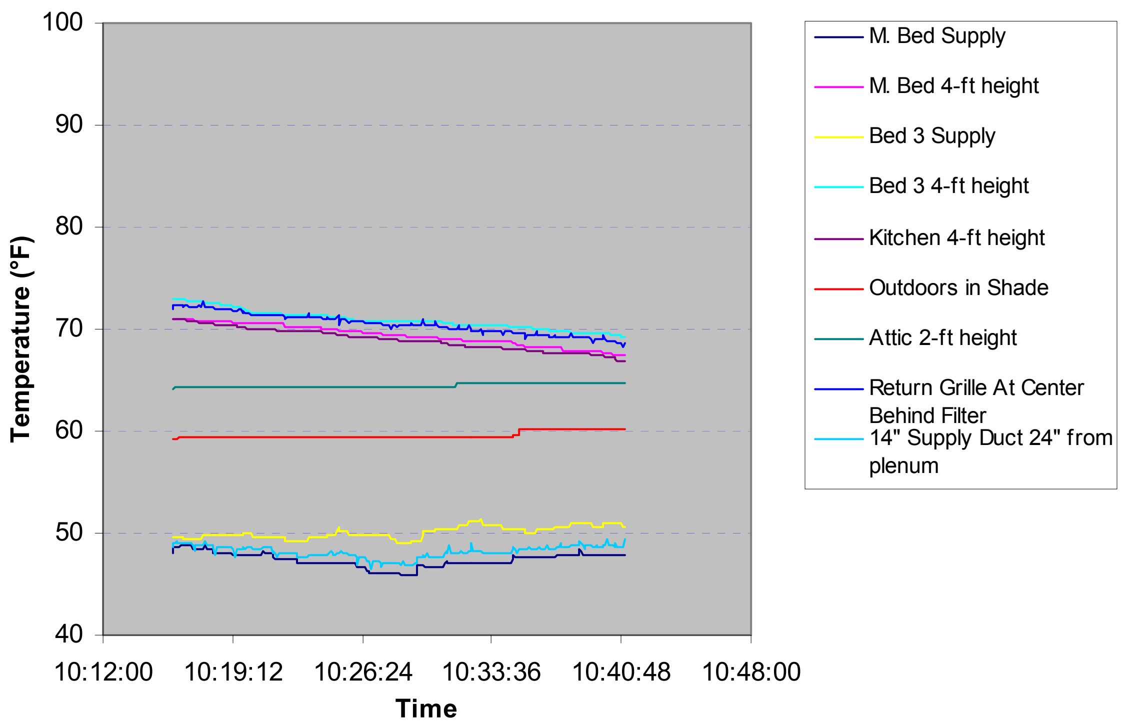
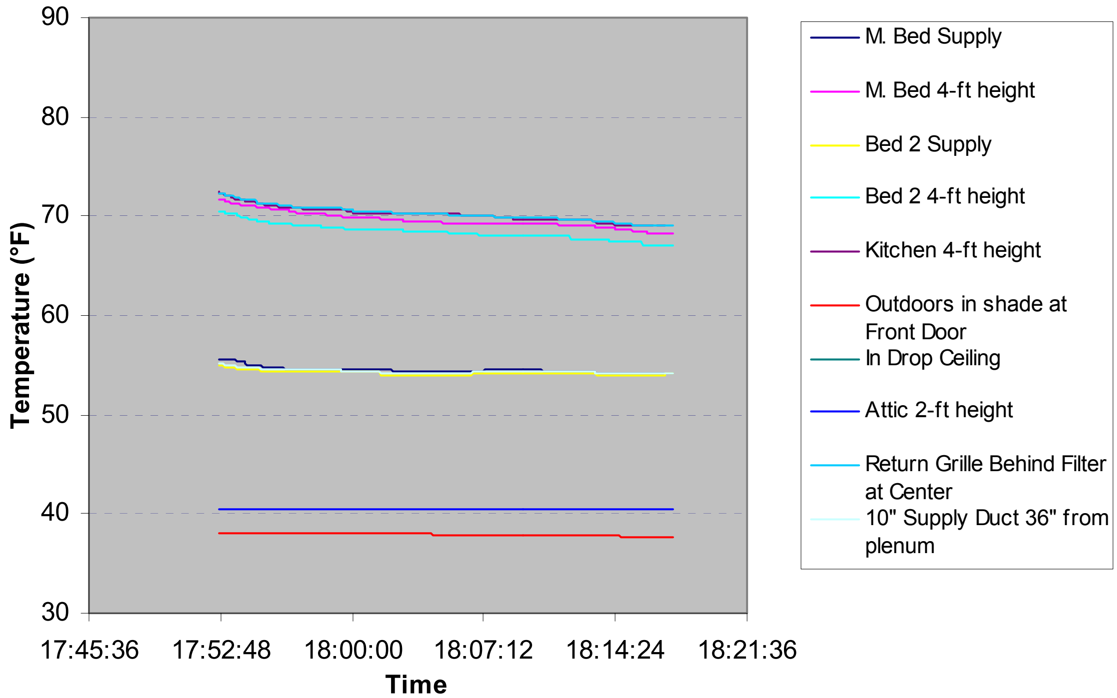


Mt. Shasta A



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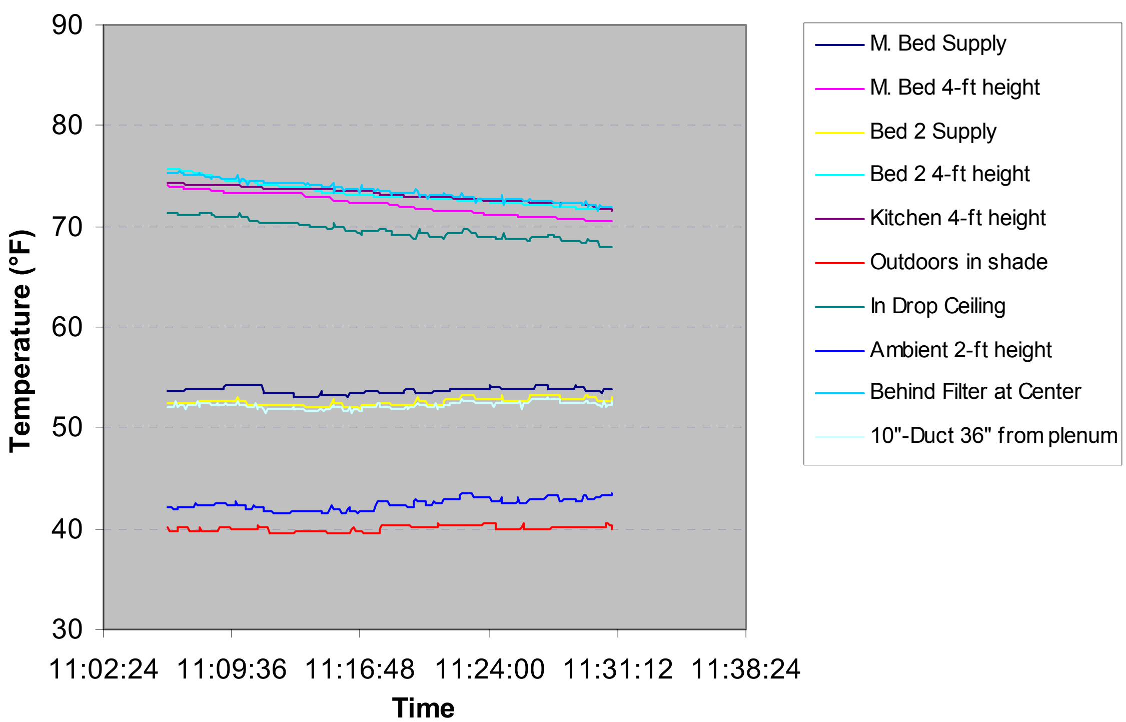
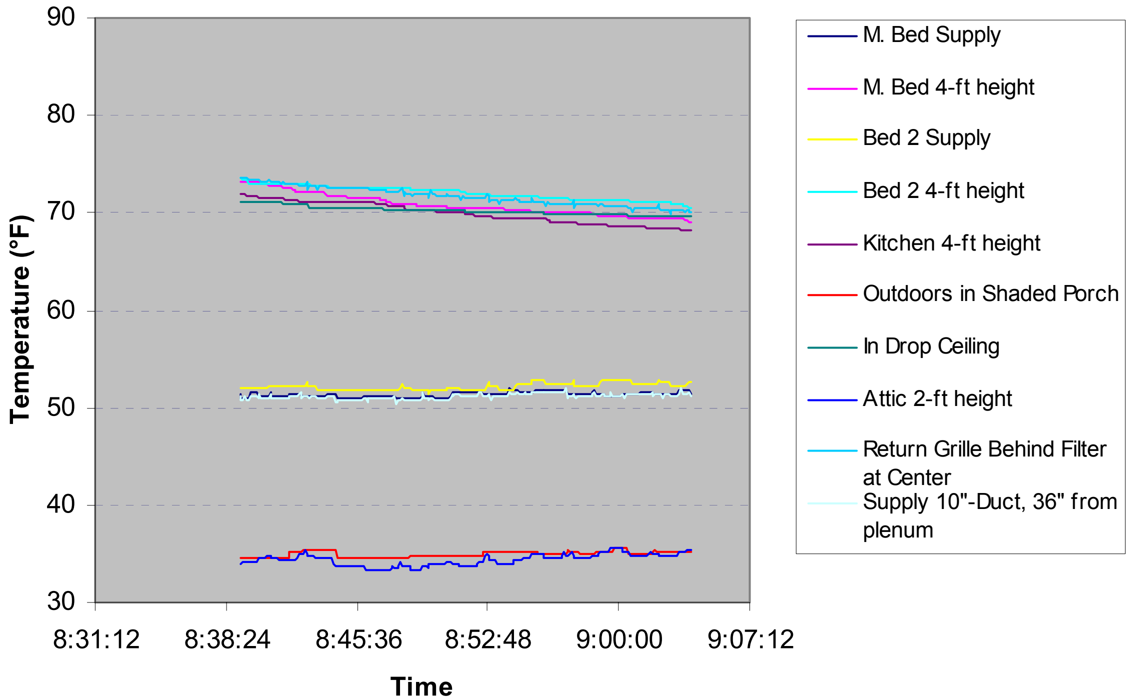
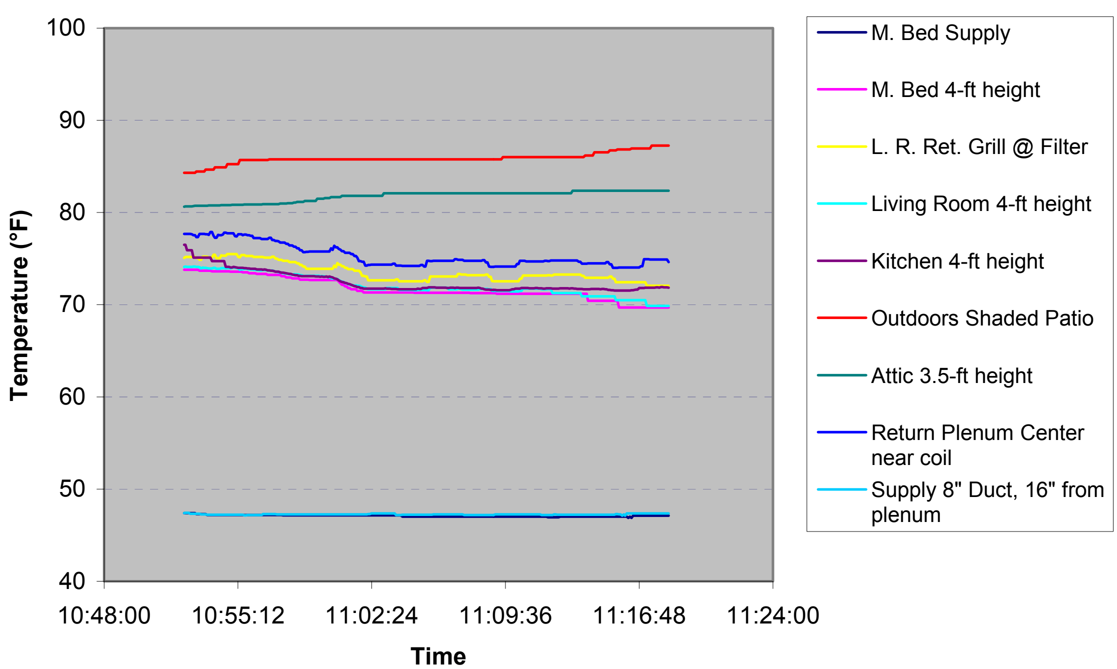


Mt. Shasta C



Redding



Element 6
Integrated Design of Residential Ducting and Airflow Systems

Literature Search Summary Report

Objectives

The literature review is intended to identify previous work on ducts in conditioned space, and guide the efforts of this project. In particular, there were three objectives:

- Identify approaches used in other projects to construct homes with ducts inside conditioned space.
- Identify builders and researchers who were involved in constructing projects with ducts in conditioned space.
- Identify information on issues related to the success of the projects such as lessons learned, problems identified and overcome, and market or technical barriers.

Literature Found

Literature describing projects built with ducts in conditioned space and methods available to build homes with ducts in conditioned space were found from four sources. The items found and their sources are listed below. Each of the items is discussed in more detail later in the document, grouped by source.

National Association of Home Builders Research Center

A Builder's Guide to the Placement of Ducts and HVAC Equipment in Conditioned Spaces

Field Evaluation of PATH Technologies: K. Hovanian's Idea House, Freehold, New Jersey

Final Report for Field Evaluation of PATH Technologies: Warren Builders' Homes, Albertville, Alabama

http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1308&DocumentID=2092, "HVAC Equipment and Duct Installation within Conditioned Space," 12/13/2001

http://www.nahbrc.org/tertiaryR.asp?TrackID=&DocumentID=2725&CategoryID=1416, "PATH: Sustainable Community in Tucson Opens, Performance Monitoring Underway," 12/13/2001

Building Science Corporation

http://www.buildingscience.com/resources/roofs/roofs_unvented.htm, "Unvented Roof Systems," 2/8/2002

http://www.buildingscience.com/resources/roofs/attics_hotclimate.htm, "Vented and Sealed Attics in Hot Climates," 2/8/2002

Steve Winters Associates (Articles in ASHRAE Journal and Energy Design Update)

"*Cost-Effective, Energy-Efficient Residence*," ASHRAE Journal, April 2001

"*Cost Effective Efficiency in Houston*," Home Energy, November/December 2001

"*Mercedes Homes Deploys Innovative New Truss*," Energy Design Update, March 2001

http://www.carb-swa.com/carbfax.html, provides access to a monthly newsletter describing various projects. Pertinent issues include September 1999, December 1999, June 2000, September 2000, October 2000, November 2000, February 2001, April 2001, May 2001, July 2001, and December 2001

Home Energy Magazine Online

http://www.homeenergy.org/archive/hem.dis.anl.gov/eehem/95/951104.html, "Researchers Approach Builders on Duct Location," 1/4/2002

"A Builder's Guide to the Placement of Ducts and HVAC Equipment in Conditioned Spaces" is a 40 page book from the NAHB Research Center describing the various ways ducts can be built in conditioned space. The book describes, in general terms, five different approaches, two of which are further subdivided. These approaches are:

- Basement Trunk and Branch
  Place the ducts in a conditioned basement, along with the HVAC equipment. Ducts then run up through the floor or in interior walls.
- Dropped Ceiling Ducting
  Use dropped ceilings, soffits or other bulkheads to conceal ductwork. Requires the use of elevated ceilings or acceptance of 7' or 7.5' ceilings in hallways. Equipment can be located in an equipment room on the main floor, off the garage in an insulated equipment room, or in the dropped ceiling. The main supply trunk is located along a hall in the dropped ceiling, with supply branches to interior wall registers. For two story homes, risers run up interior walls.
- Ducts in Slab
  Ductwork is placed prior to concrete being poured for the floor slab. Specially designed PVC fitting may be used. Slab edge insulation is needed to maintain the slab as part of the conditioned space. This approach requires early involvement of the HVAC contractor.
- Relocated Thermal Envelope
  In general, this approach uses insulation installed so as to bring areas that are normally outside conditioned space inside, and then locate equipment and ducts there. Specific examples cited include:
  - Attic
  - Crawl space
  - Knee wall
- Floor Ducting
  Use the space available in floor trusses or engineered wood joists. Two approaches are described.
  - Floor Truss Ducting

Use the space in trusses to run ducts beneath floors.

- Floor Truss Plenum
  Seal the entire area containing the trusses and use it as a supply plenum, minimizing duct costs. This requires careful attention to insulating the perimeter and sealing all joints. Testing is recommended to assure achieving adequate tightness.

Advantages cited for the various approaches include enhanced marketability, lower equipment cost from equipment downsizing, and meeting energy codes more easily.

In addition to the descriptions and discussion of the various approaches, several profiles of projects built with ducts in conditioned space are provided. These include the builder, builder's location, and approach used, along with other details of the project. The table below summarizes these projects.

Builder	**Builder's location**	**Approach Used**
Stitt Energy Systems	Rogers, AR	Floor Truss Ducting Ducts in Slab Floor Truss Plenum
DeLuca Enterprises	Newtown, PA	Floor Truss Ducting
Bob Ward Companies	Edgwood, MD	Basement
Pulte Homes of Minnesota	St. Paul, MN	Dropped Ceiling
Ryan Homes	Rochester, NY	Basement Dropped Ceiling Floor Truss Ducting
Bobroff Housing Concepts	Gainesville, FL	Dropped Ceiling
Pulte Homes – Las Vegas	Las Vegas, NV	Conditioned Attic
Battlefield Homes	Fredericksburg, VA	Conditioned Crawlspace
Hedgewood Properties	Atlanta, GA	Conditioned Crawlspace w/ Floor Truss Ducting
BBH Enterprises	Carrollton, TX	Floor Truss Plenum, w/ Dropped Ceiling Return Plenum
R. E. Collier	Richmond, VA	Conditioned Crawlspace

The book also discusses code issues related to ducts in conditioned space. Most of this material is focused on crawlspace issues, as most codes require crawlspace ventilation. There is discussion of floor truss related issues also.

NAHBRC is participating in demonstration projects of a variety of new home construction technologies through the PATH program (Partnership for Advancing Technology in Housing). Their website (www.nahbrc.org) contains descriptions of a number of projects, several of which mention ducts in conditioned space.

A page discussing ducts in conditioned space summarizes some of the material from the "*Builder's Guide . . .*" discussed above. In addition, however, it lists three field evaluation sites: Hughes Construction, Lexington, NC; K. Hovnanian Inc, College Park Estates, Freehold Township, NJ; and Warren Builders, Site 1, Albertville, AL.

No duct system details are provided for Hughes Construction. K. Hovnanian Inc., installed the main supply trunk duct in a bulkhead below the second story floor joists. A minimized distribution system was used. High throw registers were used to assure good mixing in the space. Warren Builders in Alabama built two homes which were identical except for ducts in the conditioned space with a mechanical ventilation system. Installation costs for the two duct systems were very similar, except the duct in conditioned space house required return visits from the framer and drywall contractor to frame and drywall the bulkhead around the duct system. Duct losses to outside at 25 Pa were 15 cfm vs. 274 cfm for the house with the attic system.

An additional project mentioned on the site was Armory Park del Sol. This is a sustainable community of 99 single family homes in Tucson. Among other features, it uses ducts in conditioned space, but no specifics are given.

Full reports (in draft form) describe two of the project in more detail. *Field Evaluation of PATH Technologies: K. Hovanian's Idea House, Freehold, New Jersey*, discusses several technologies, including ducts in conditioned space. As mentioned above, the duct system was installed in a bulkhead below the second floor joists. A problem was that ductwork had to be routed through the heated (but not air-conditioned) garage in order to reach a family room. Duct leakage to outside was higher than expected, possibly due to this section in the garage or because of penetrations in floor or wall cavities to the outside.

Final Report for Field Evaluation of PATH Technologies: Warren Builders' Homes, Albertville, Alabama, again discusses several technologies, including ducts in conditioned space. This project consisted of two homes, identical except for the technologies being evaluated. For installing the ducts in conditioned space there was concern about ensuring the duct space was isolated from the outside. To achieve this, the ceiling of the space was drywalled, then the duct system was installed. Framers and drywallers then returned to install the bulkhead below the ductwork. The need for return visits by the framers and drywallers was identified as a problem, and was the cause of the cost increase for this approach versus the conventional house. Differences in cost to the builder were identified as follows: HVAC materials - \$51 savings, HVAC Labor - \$2.50 savings, Framing impacts - \$50 increase, Drywall impacts - \$282 increase. The effort to isolate the system from the outside, however, was successful. As mentioned above, duct losses to outside at 25 Pa were 15 cfm vs. 274 cfm for the house with the attic system. Energy simulations showed a \$20 per year savings.

Another source of literature was the Building Science Corporation website (www.buildingscience.com). Joe Lstiburek of Building Science is working with Pulte on their Building America project which uses conditioned unventilated attics so conventional attic duct systems are inside conditioned space.

"*Unvented Roof Systems*" provides details on how such systems are insulated in various climates. In climates where the monthly average temperature falls below 45°F, insulation above the roof deck is used to prevent condensation on the underside of the roof deck. In climates with minimum average monthly temperatures above 45°F, such insulation is not used. 45°F is the dewpoint of 70°F, 40% RH room air. Keeping the roof deck above this temperature avoids condensation when the room air contacts the roof deck. The monthly average temperature is used because it is felt that short term spikes of cold weather will not create a problem. "Wood based roof sheathing typical to residential construction has sufficient hygric buffer capacity to absorb, redistribute and re-release significant quantities of condensed moisture should intermittent condensation occur during cold nights when the sheathing temperature occasionally dips below 45 degrees F." Based on the coldest average monthly temperature, the minimum ratio of insulation above and below the roof deck is specified.

"*Vented and Sealed Attics in Hot Climates*" argues that using the roof as both the rain barrier and air barrier is a cost effective means of providing a good air barrier. In conventional construction, the air barrier is the taped drywall of the ceiling, while the thermal barrier is the insulation above it. Because the ceiling is not a continuous plane, but is a series of horizontal planes, knee walls, and sloped planes, it is very difficult to maintain contact between the air and thermal planes. This allows air movement through the insulation, minimizing its effectiveness. The article discusses building code requirements for attic ventilation, with the rationale behind the requirements. The bulk of the article focuses on computer simulations of energy performance of sealed attics in hot climates, showing no energy penalty.

Steven Winters Associates has also been involved with a number of projects involving ducts in conditioned space. Several of their projects are reported in multiple publications.

"*Cost-Effective, Energy-Efficient Residence*," ASHRAE Journal, April 2001, by Dianne Griffiths and William Zoeller, describes a demonstration home built in the Houston area under the Building America program. This is a 2,506 ft² home, two story slab on grade, that incorporates a number of energy efficiency measures. The air handler is located on the second floor, with all ducts in the truss space between the first and second floors. An engineered wood floor system uses 14 in. deep I-joists to provide room for the ducts. It is not clear how ducts penetrate the I-joists. Ceiling supply registers are used for the first floor and a combination of high sidewall and floor registers are used on the second floor. The system has a single return. The system used a combination space/water heating system was used with the gas water heater in the attic.

The same house, known as the Carbury, is discussed in "*Cost-Effective Efficiency in Houston*," in Home Energy magazine, November/December 2001. This article provides some additional detail in terms of the monitoring program and comparisons to a control home. The builder is Beazer Homes.

"*Mercedes Homes Deploys Innovative New Truss*," Energy Design Update, March 2001, describes a house built in central Florida using a number of innovations. Mercedes

Homes, in Melbourne Florida, built the house using a truss system manufactured by Space Coast Truss, a Mercedes subsidiary. The trusses are built with a portion of the bottom chord raised to allow for construction of a mechanical plenum. The plenum ran nearly the full length of the house, and about the center 1/3 of the width. The interior of the plenum was lined with 1/16-inch Thermoply, a laminated sheathing. Batt insulation on the sides of the plenum were extended above the top of the plenum, forming a dam for the blown in fiberglass on top of the plenum. The plenum contained the air handler and all ductwork, which used interior ceiling register locations throughout.

A number of other projects are described on the Steven Winters Associates web site, www.swinter.com. Most of these project descriptions include various construction and energy conservation technologies. Details on ducts in conditioned space are usually sparse. The table below lists the projects by builder and location that are said to have ducts in conditioned space, with any additional information available.

Mercedes Homes	Melbourne FL	Some ducts buried in attic insulation
Samson Designs	Louisville KY	Dropped ceiling
Del Webb	Sun City AZ	Ductwork on roof truss bottom chord buried within R-38 insulation
Mercedes Homes	Melbourne Beach FL	Townhouses
Cambridge Homes	Crest Hill IL	Dropped soffits
Advanced Laminated Housing	Wakarusa IN	
Crosswinds Communities	Detroit MI	
Mitchell Homes	Pensacola FL	Mini-ducts in conditioned space
Beazer Homes	Sacramento CA	

Steven Winter Associates is also working with Steel Floors, Inc., based in Colorado, to develop steel joists designed to allow ducts, piping and wiring to pass through. The new joists have cutouts of 23” by 10-1/4.”

“*Researchers Approach Builders on Duct Location*,” Home Energy Magazine Online, November/December 1995, describes the results of a study conducted by LBNL. The team attempted to persuade 12 California builders, who represented “a substantial portion of 1995 California building starts” to incorporate ducts in conditioned space using a dropped ceiling in single story homes or truss space ducts for multi-story homes. Builders were interested in the project, but believed that the projects would result in a net cost increase. A number of issues were cited.

- Extra labor to seal the space containing the ducts.

- Timing of duct installation – early installation may result to duct damage during subsequent construction.
- Installation in truss spaces built with metal trusses may result in duct damage from sharp edges.
- Cost sensitivity – builders unwilling to accept higher construction costs.
- Aesthetic concerns with using soffits. Dropped ceiling approach considered more workable, but there were concerns about rooms that were not adjacent to the central hall.
- Verification of energy efficiency measures was cited as a concern by a builder of upscale homes. He builds energy efficient homes and wants that reflected in a standard verification process. He believed that competing houses were being certified as energy efficient through a utility program regardless of the quality of the efficiency measures installed. He felt that marketing houses with ducts in conditioned space, as well as other efficiency measures, would be more effective if savings were verified.
- Energy measures which require involvement by multiple parties to the construction process – architect, framer, insulator, and HVAC contractor – face significantly larger market barriers than do those that are easily installed by a single trade.

Summary

The good news: A number of research and demonstration projects have included building homes with ducts in conditioned space. A variety of techniques have been used. NAHB Research Center has provided good descriptive material describing the various approaches including advantages and disadvantages. There appear to be a fair number of existing homes with ducts in conditioned space from which we can possibly obtain data or gain access for testing.

The bad news: Little detailed or specific information is available. None of the literature found provides sufficient detail to allow a builder to confidently undertake construction of a home with ducts in conditioned space. Several articles cite problems encountered in constructing the demonstration homes, but little guidance is provided beyond early involvement of all the affected trades. Little test data is provided, with the data provided generally along the lines of air leakage to the outside. No details of testing performed or results obtained are provided.

A number of builders involved in projects are identified, but no contact information is provided. Contact points within the small number of research organizations are identified. If the research organizations are not cooperative in providing contact information or assisting in obtaining access to the builders, it may be difficult to gain access for testing.

For those projects where energy performance results are provided, ducts in conditioned space appear to perform well. This may indicate that good energy performance is fairly robust, boding well for successful implementation of a future CEC program.

Unfortunately, alternative explanations are also possible, such as the presence of research teams ensure high quality installations that might not occur in production practice.

Interviews with Builders and Researchers

Submitted to:
New Buildings Institute
www.newbuildings.org

Integrated Energy Systems
Productivity and Building Science

On behalf of the:
California Energy Commission
Public Interest Energy Research (PIER) Program

October 24, 2002

Integrated Design of Residential Ducting and Airflow Systems
Roger Hedrick

GARD Analytics
Energy, Economic and Environmental Research

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Project Director: Roger Hedrick, GARD Analytics, Inc.

Technical Assistance: Geof Syphers, XENERGY; Rob Hammon, Con-Sol; Bill Irvine, BCI Testing.

Review and Advisory Committee: Rick Chitwood, Chitwood Energy Management; Iain Walker, Lawrence Berkeley National Laboratory; Joe Lstiburek, Building Science Corporation; Bruce Wilcox, Berkeley Solar Group; Jamie Lyons, National Association of Home Builders Research Center; Marshall Hunt, Pacific Gas and Electric.

Project Management: Cathy Higgins, Program Director for the New Buildings Institute and Don Aumann, Contract Manager for the California Energy Commission.

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ABOUT PIER

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission, annually awards up to $62 million to conduct the most promising public interest energy research by partnering with research, development and demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

1. Buildings End-use Energy Efficiency
2. Industrial/Agricultural/Water End-use Energy Efficiency
3. Renewable Energy
4. Environmentally Preferred Advanced Generation
5. Energy-Related Environmental Research
6. Strategic Energy Research.

This project contributes to #1 above, the PIER Buildings Program Area. For more information on the PIER Program, please visit the Commission's Web site at: www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200. For other public reports within the *Integrated Energy Systems — Productivity and Building Science* project, please visit www.newbuildings.org/PIER

LEGAL NOTICE

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OBJECTIVES

This report describes the results of interviews conducted with builders and researchers involved in projects building homes with ducts in conditioned space. The interviews were conducted with the goals of:

- Identifying various means of building homes with ducts in conditioned space
- Identifying technical problems encountered and approaches used to resolve them
- Identifying market barriers encountered and means to overcome them

INTRODUCTION

New homes built in California typically are built with the air handler and ductwork located in the unconditioned attic. The ductwork is commonly built with ductboard plenums and flex duct, insulated to R4. In recent years, numerous studies have found large energy losses from these systems, primarily due to air leaks in the air handler and duct system, but also including heat conducted through the duct material. These losses are especially deleterious in the summer when solar radiation can elevate the attic temperature well above the outdoor air temperature. Previous studies have found that typical duct systems can lose as much as 40% of the space conditioning energy consumed by the HVAC system.

Air leaks on the supply side of the system are lost to the unconditioned attic and eventually to the outdoors, while leaks on the return side result in unconditioned air being brought into the system, increasing the space conditioning load. Unbalanced leakage (for example, large supply leaks with small return leaks) can significantly affect the air pressure in the house resulting in increased infiltration and the corresponding increase in space conditioning loads.

The problem of duct leakage has primarily been addressed through a variety of programs aimed at reducing leakage in the duct system. These approaches, however, still result in ducts located in the unconditioned attic, exposed to extreme temperatures due to outdoor temperatures and solar gains. Taking the next step of placing the ducts inside conditioned space, offers the opportunity to further improve the energy performance of the system.

Placing ducts inside conditioned space requires changes from conventional building practice in a number of areas. It is expected that as homes are built with ducts in conditioned space, that problems will be identified and opportunities for improved methods developed.

To date, relatively few homes have been built with ducts in conditioned space. An exception to this statement is homes with systems in basements, common in northern climates. In California, however, most homes are built with a slab on grade, and the duct system in the attic. Pulte Homes, working with the USDOE Building America Program, has been building homes in Arizona, Nevada and now California, putting the ducts and air handler in an Unvented Conditioned Attic. A few homes have also been built using the Dropped Ceiling approach, mostly in the southeast, again in cooperation with

Building America. Finally, some homes have been built in the Shasta, California area with insulation and HVAC work done by Rick Chitwood, using Dropped Ceilings.

INTERVIEWS

John Drew, Regional Manager, Pulte Homes

Discussed Pulte's projects in California which include ducts in conditioned space. They are using the Environments for Living Program, under which they build houses to one of three efficiency levels: Silver, Gold or Platinum. The distinction is made at the development level, i.e., all the homes in a particular development are built to the same efficiency level. The Platinum homes include ducts in conditioned space. This program provides a guarantee on heating and cooling energy use.

They have worked with Building Science Corporation under the DOE Building America program, and are using the unvented conditioned attic approach. They are also including several other energy conservation design changes. They use "zero-tolerance insulation installation" where they use damp-blown cellulose with zero voids in the walls. They use UL rated netting between roof trusses, supporting dry-blown cellulose roof insulation. On the Platinum projects, they are teaching their subcontractors how to do the desired installations.

Currently there are two projects in California that are Platinum level. In Banning, houses are under construction, and in Murrieta, construction is expected to begin in July 2002.

Josh Robinson, General Superintendent, Pulte Homes, Banning, California

Josh had prior experience working at Pulte development in Arizona that used the unvented conditioned attic approach to putting ducts in conditioned space. He brought that experience, and it has been valuable in getting the project in California on the right track. The key to the success of the Banning project is getting all the subcontractors to think and work as a team. This is facilitated by the pacing of the project, which allows the subcontractors to train particular teams on the new design, and keep them busy at the project. Retaining the same contractor teams is particularly important. The subcontractors have all "bought in" to the idea of building high-quality, low energy consuming homes. They have all developed a sense of pride about the project.

Another important aspect of the success of the project is the presence of Bill Irvine, an independent contractor hired by Pulte to check the quality of the houses. He does blower door tests on at least every 6th house, although he was doing a higher fraction than that early in the project when all the subcontractors were learning. It is expected that the percentage tested will decrease later on. He serves as both a quality control checker and as a resource for the subs working on the project. The testing is required by the Environments for Living program, but provides added value as well.

Rick Chitwood, Chitwood Energy Services

Rick has built a number of homes with ducts in conditioned space in the Shasta, California area. He has primarily used the dropped ceiling approach. His firm provides both the insulation and HVAC work, so he takes the responsibility for ensuring that the ducts actually are in conditioned space.

His primary criteria for success with ducts in conditioned space is to establish the air barrier at the level of the bottom chord of the roof trusses. He has the framers put in draft stops at that level, then his firm does the sealing and insulation. At any location which will not have drywall immediately below the bottom chord of the roof trusses, such as soffits, plumbing chases, and the dropped ceiling duct space, the framers use whatever material is available as the draft stop. Usually this will be plywood or OSB. The framers simply partially drive nails horizontally into the top plates, and lay the sheet material on top. Chitwood then uses insulating foam to seal around the material. He also uses the foam to seal any holes for wiring or plumbing penetrations.

He recommends testing systems using ducts in conditioned space by pressurizing ducts and measuring leakage to outdoors, then pressurizing house and checking the change in leakage to outdoors. Ideally, it should go to zero. He wonders about Pulte testing the performance of their houses with the attic hatch open. He wonders about the impact on attic vs. house pressure. He thinks the ceiling is a significant air barrier, meaning that leakage to the attic will have partial communication with both the indoors and outdoors. Testing with the hatch open artificially increases communication with the indoors.

In California, because the humidity is low, Rick prefers to use about 450 cfm/ton, mismatching the outdoor unit with a higher cfm air handler and larger indoor coil. He feels that this improves the efficiency with a decrease in dehumidification capacity. (It would result in a higher volume of less cool air.) He also uses as large a return duct as possible.

His houses were built with interior supply register locations. This allows for savings on materials, with shorter duct runs. This works because he specifies good quality windows to avoid drafts and cold spots in the room. Good wall insulation is also necessary. He also uses higher quality registers to improve air mixing in the space.

Bill Irvine, BCI Testing

Bill does the testing of the Pulte houses in Banning. He has worked with the people from Building Science Corporation on how the homes should be built, and on the testing procedures. He is supposed to check every sixth house, on average, for the Environments for Living insurance (they guarantee the energy consumption, so they check the houses to assure performance). He was doing a higher rate than that, but expects to do fewer later in the project. He is on site at Banning about 2 days per week. He feels that the success of the project is being driven by the teamwork exhibited by the various subcontractors working together. The HVAC and insulation contractors, in particular, have had the same crews working steadily at the project, and that allows them to be trained to a fairly high level, and retain that training on site.

The production of the houses, focused on only two plans with few significant options, allows the HVAC contractor to prepare ductwork materials ahead of time, pre cutting them to the correct length for installation in the field. This helps with the HVAC quality because everything fits well.

He serves as a quality control inspector and coach to the subcontractors. As the subs have turnover on their crews, he helps to assure that the new people are doing the work properly.

For the Environments for Living program, Bill tests the whole house with a blower door. He takes the CFM_{50} both with the hatch open and closed. His primary concern is overall envelope tightness. In addition, with the HVAC system operating, he checks static pressures: return duct to attic, supply to attic, between rooms with the doors closed, indoor to outdoor. The room to room pressures must be less than 3 Pa with the air handler on, in order to check that the return air jump ducts are installed properly and allowing return air to flow properly from all rooms.

To test the duct leakage to the outdoors, Bill would use the following procedure:

1. Block all supply registers
2. Install a duct blaster on the return air intake
3. Install a static pressure sensor in the duct system
4. Use a blower door to pressurize the house to 25 Pa
5. Use the duct blaster to get the duct system to 0 Pa relative to the house (0 Pa across the duct blaster)
6. Read the leakage to outdoors from the duct blaster

He is willing to help us arrange for and conduct the testing at Banning.

Jamie Lyons, NAHB Research Center

NAHBRC has worked with a few builders on projects putting ducts in conditioned space. They prepared reports and web articles on some of these projects, which were discussed in the literature review. Issues identified were availability of improved registers for use with interior register locations, and subcontractor coordination.

Joe Lstiburek, Building Science Corporation

Joe is working with Pulte through the Building America program to improve the efficiency of residential construction. He has done a lot of work on moisture issues in residential construction, and has numerous items on the Building Science website. He believes that the unvented conditioned attic approach is superior in that it is more robust. This is because an air barrier that already exists, the roof deck, is used instead of a new air barrier. He feels that a new air barrier added between the roof and ceiling, as is done with the dropped ceiling and plenum truss approaches, is more likely to be leaky.

Joe referred me to Pulte homes in Banning, and provided contact information to John Drew. He also referred me to Armin Rudd for data.

Armin Rudd, Building Science Corporation

Armin told me that Pulte is testing every sixth home for performance in order to provide the guarantee on energy consumption. Building Science has accumulated a database of test data that is in a 13 Mbyte Excel file. He will see if he can get me a copy.

Taghi Alereza, ADM

ADM is working under a CEC contract to assist Habitat for Humanity in developing energy conservation features that can be inexpensively applied to single family Habitat houses. They are looking at ducts in conditioned space as one feature, with the decision between furring up and furring down (dropped ceiling) duct spaces.

Later, they told me that they are going with a dropped ceiling design, but they plan to use the dropped ceiling space as a supply plenum without ducts. The air handler will be located in the attic, with a duct into the plenum. They are concerned about possible moisture problems, and sealing of the dropped ceiling plenum.

Diane Griffiths, Steven Winter Associates

They are working with builders under the Building America program. They worked with Mercedes homes on ducts in conditioned space. Mercedes tried some dropped ceiling plans, some of which did not work. This was due to sealing problems.

They also worked with Mercedes on the plenum truss system. A first design was used for 6 houses. Limited testing was done on these. Based on these first 6 houses, they are redesigning the trusses.

They also worked on the “Carbury” model house in Houston. This was the subject of articles in Home Energy and other publications. It is a two-story home that uses a combo system (gas water heater supplying a hot water coil in the air handler). The water heater is in the attic, with the air handler in a second floor closet supplying ducts located in the truss space between the first and second floors.

Diane recommended I speak to Bill Zoeller for additional details on ducts in conditioned space.

Bill Zoeller, Steven Winter Associates

I talked to Bill about the redesign of the plenum truss system. They most recent version uses a modified scissors truss. This gives a large flat area on which to install the upper air barrier, above the ceiling. Insulation is blown in on top of the air barrier. They used the system on one house, where they used fiberboard for the air barrier. Cost is an issue with this approach. They change to the scissors truss was driven by cost, and he is still concerned about the fiberboard being too expensive. He feels that some sort of roll material may work and be less expensive.

Janet McIlvaine, Florida Solar Energy Center

FSEC monitored the performance of a number of house built using a dropped ceiling for the ducts. They worked with three builders. One builder in North Carolina had five homes with the dropped ceiling and five without. Another in Florida had five houses with dropped ceilings, and a builder in Texas had 10 houses with ducts in conditioned space. The first two of these were Habitat for Humanity homes, the Texas builder was doing custom homes, which were much larger. An article in Home Energy discussed this work to some extent. She will send me a final report which will have test data.

The approaches to building ducts in conditioned space were developed by the builders, FSEC only tested the results and did some on-site observations during construction. In general, the builders tried to make the duct space tight to itself, i.e., they were concerned with establishing an air barrier at the sides, and possibly the bottom, of the duct space. FSEC found, however, that airtightness of the duct space, particularly at the top (connecting to the attic) was severely compromised. This was primarily due to later penetrations being created for plumbing or wiring. There was a lack of understanding of the concept on the part of the various trades. Janet believes that a sense of teamwork needs to be established among all the trades, and someone must be assigned to assure that the duct space is sealed.

Janet believes that testing was also a problem. They had planned to do standard tests for duct leakage to outdoors. They were not able to pressurize the duct space, however, which she believes compromises the ability to judge leakage to outdoors under operational conditions. The report she is sending will have all the test data.

Representative House Designs Summary Report

by
Roger Hedrick
GARD Analytics, Inc.

May 16, 2002

Submitted to:
New Buildings Institute
Integrated Energy Systems
Productivity & Building Science Program
Contract Product Number 6.3.3

On behalf of the
California Energy Commission
Public Interest Energy Research (PIER) Program
Contract Number 400-99-013

Element 6
Integrated Design of Residential Ducting and Airflow Systems

Identify Representative House Designs Summary Report

Objectives

This task is intended to identify house designs that are typical of houses currently being built in California. These house designs will then be used in later tasks as the basis for cost estimates and energy and energy cost savings estimates for modifying the construction to include ducts inside conditioned space.

The typical home designs are to include one story detached homes, two story detached homes, and two story townhomes. These houses have conventional duct systems in the unconditioned attic. Most of the designs are slab on grade, although one design has a partial crawlspace. Later tasks will include identification of which methods of constructing ducts inside conditioned space are appropriate for each design. Multiple methods may be evaluated for a given design.

Home Designs

ConSol worked with California builders to select a number of home designs. The designs were selected on the basis of ConSol's experience in performing energy analyses in homes across the state for many different builders. They determined that these designs represent the market well, as segmented by type and floor area.

For each of these designs, permission was obtained form the builder for the designs to be used for this project. These are copywrited designs, however, and may not be used for any purpose beyond the scope of this project. The builders are not identified

Architectural drawings were provided in paper form, and mechanical designs were provided electronically. The floor area, number of bedrooms and bathrooms and number of floors of the designs is described below. Also shown are the HVAC system design drawings which show floorplans.

Table 1 – Summary of Major Characteristics of the Representative Home Designs

Design #	Type	Design Name	Floor Area	Bedrooms	Bathrooms
1	1 Story	Gainsborough West (2)	1733 ft²	3	2
2	1 Story	Terra Linda	1746 ft²	3	2
3	1 Story	Los Olivos	3079 ft²	4	3
4	2 Story	Gainsborough West (1)	2231 ft²	4	3
5	2 Story	Mayfair/ Oak Glen II	3148 ft²	6	3
6	2 Story	Windmere Village 10	3194 ft²	5	3½
7	Townhome	Georgetown, Unit B	1584 ft²	3	3
8	Townhome	Sansovino, Unit 2	1216 ft²	2	2

9	Townhome	Avendale P-3, Plan 2	1570 ft²	3	2½

Design #1 – Single Story

Gainsborough West (2) - 1733 square feet, 3 bedrooms, 2 baths.

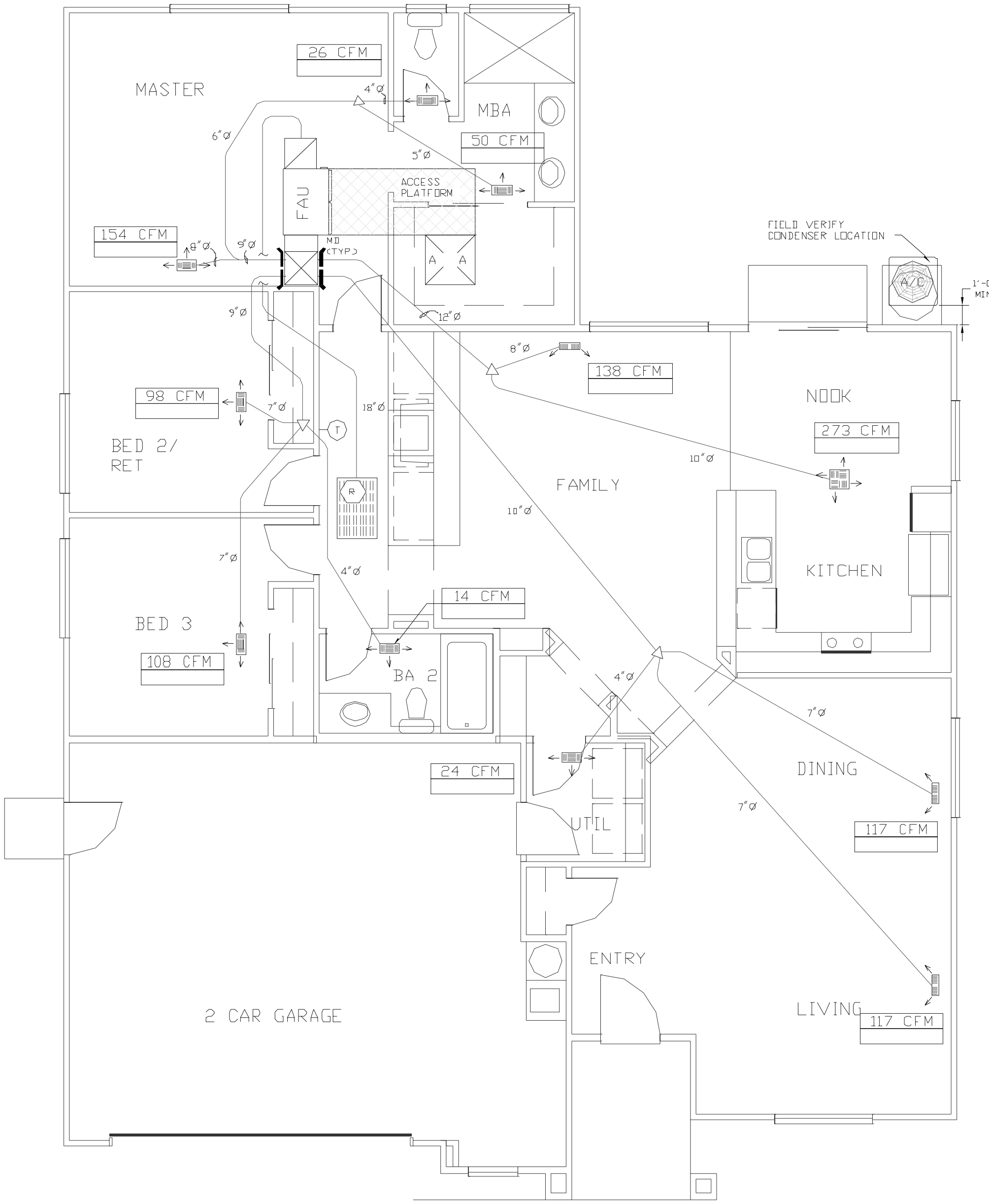

Figure 1 - Design 1, HVAC Design

Design #2 – Single Story

Terra Linda - 1746 square feet, 3 bedrooms, 2 baths.

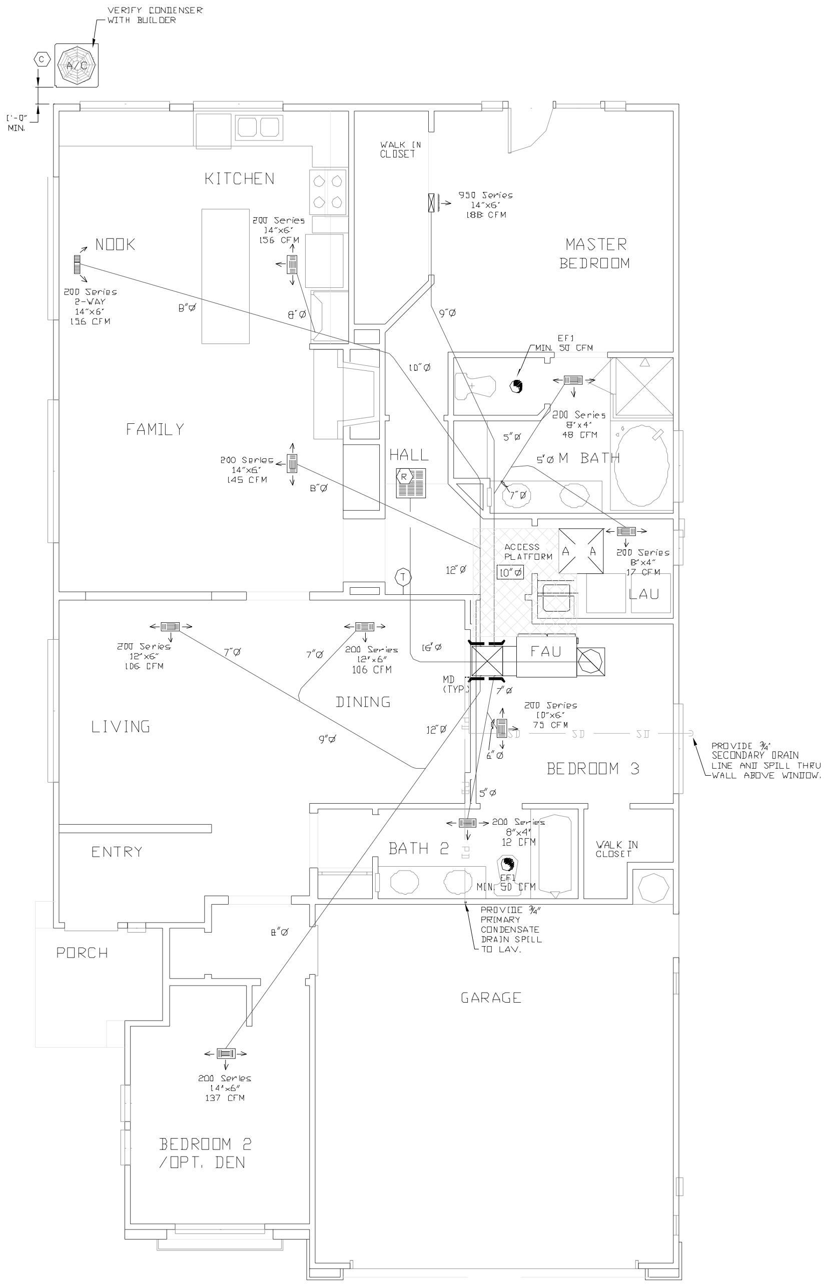

Figure 2 - Design 2, HVAC Design

Design #3 – Single Story

Los Olivos, Plan 1A - 3079 square feet, 4 bedrooms, 3 baths.

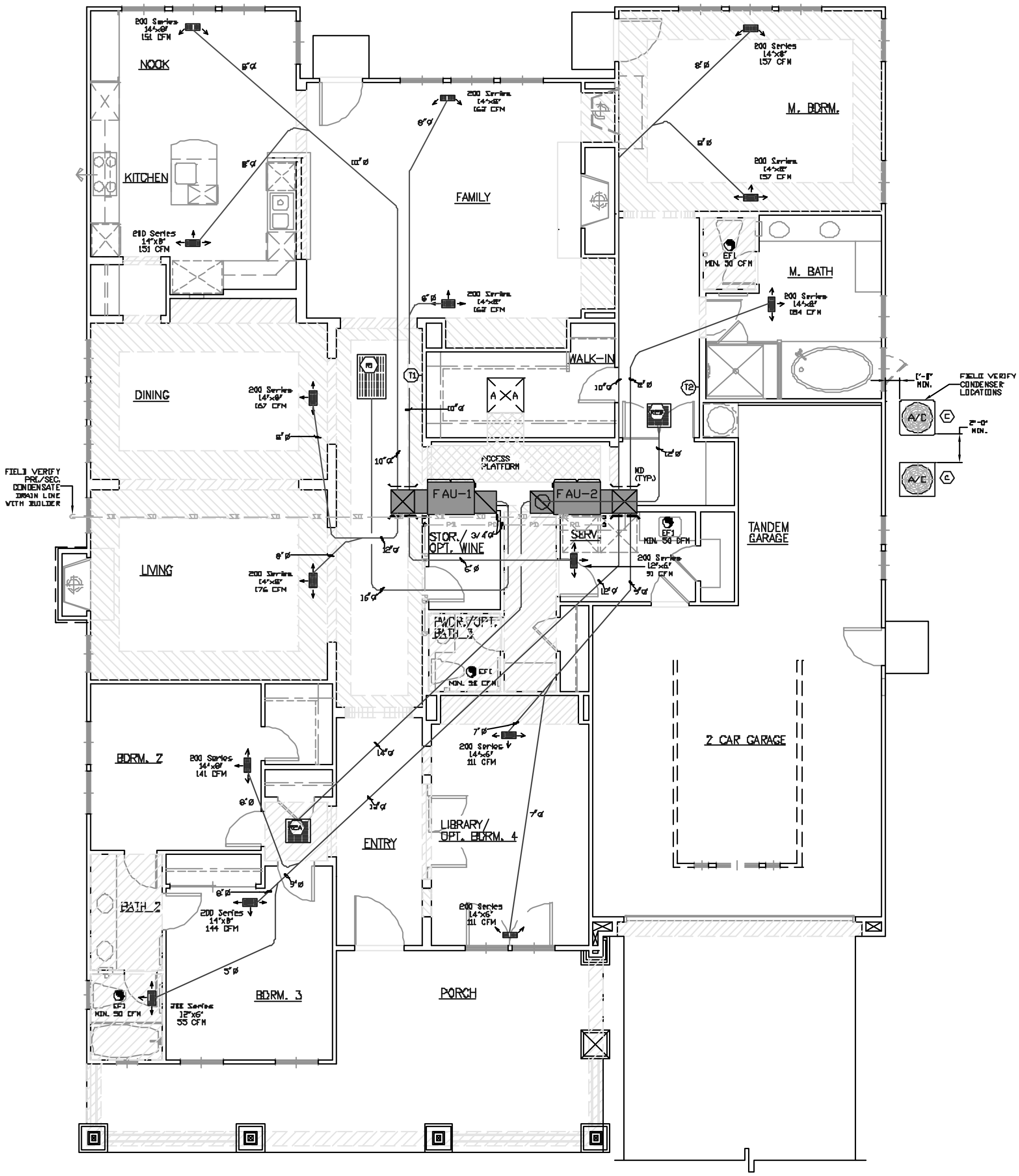

Figure 3 - Design 3, HVAC Design

Copywrited designs shown are not to be used outside the scope of this project.

Design #4 – Two Story

Gainsborough West (1) - 2231 square feet, 4 bedrooms, 3 baths.

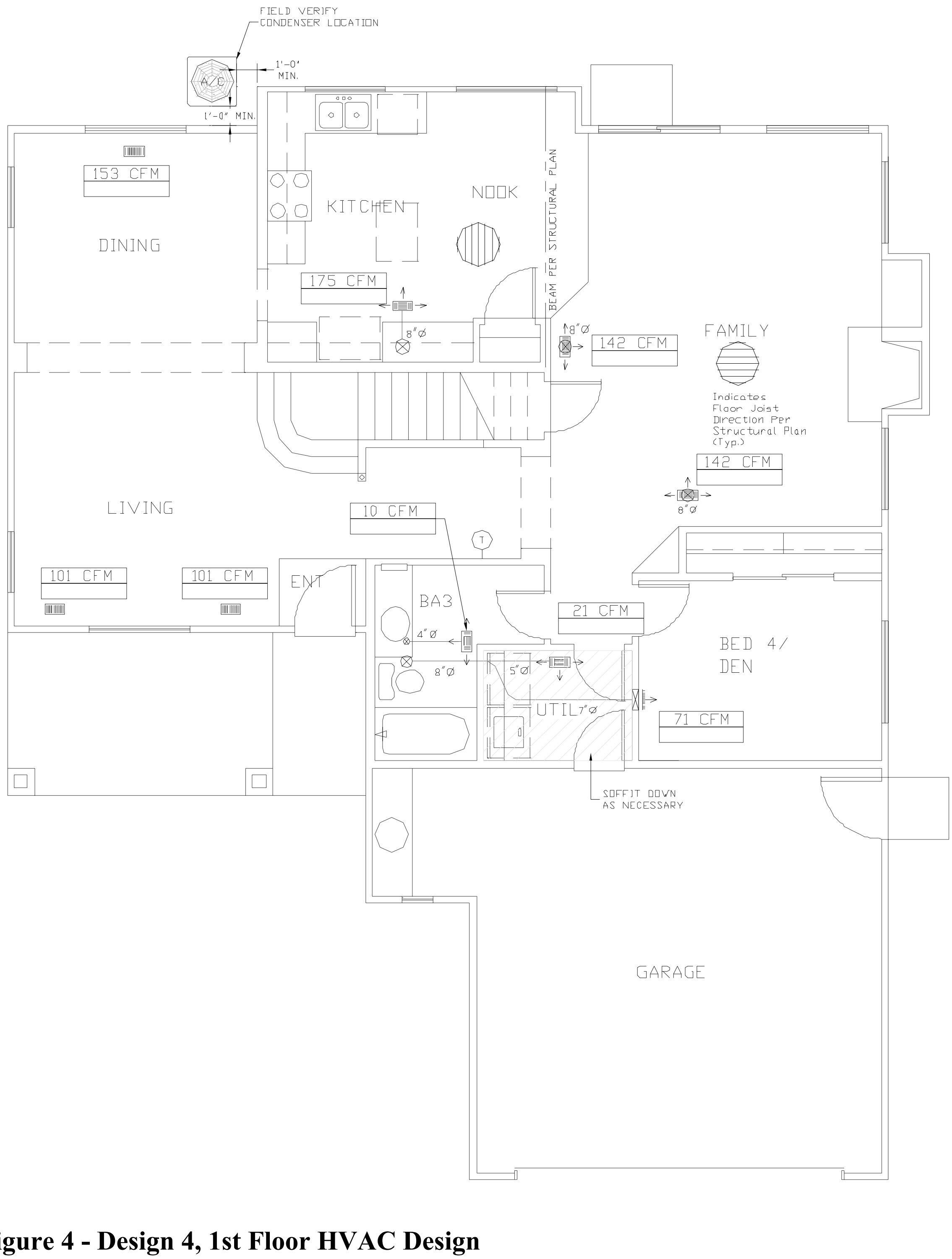

Figure 4 - Design 4, 1st Floor HVAC Design

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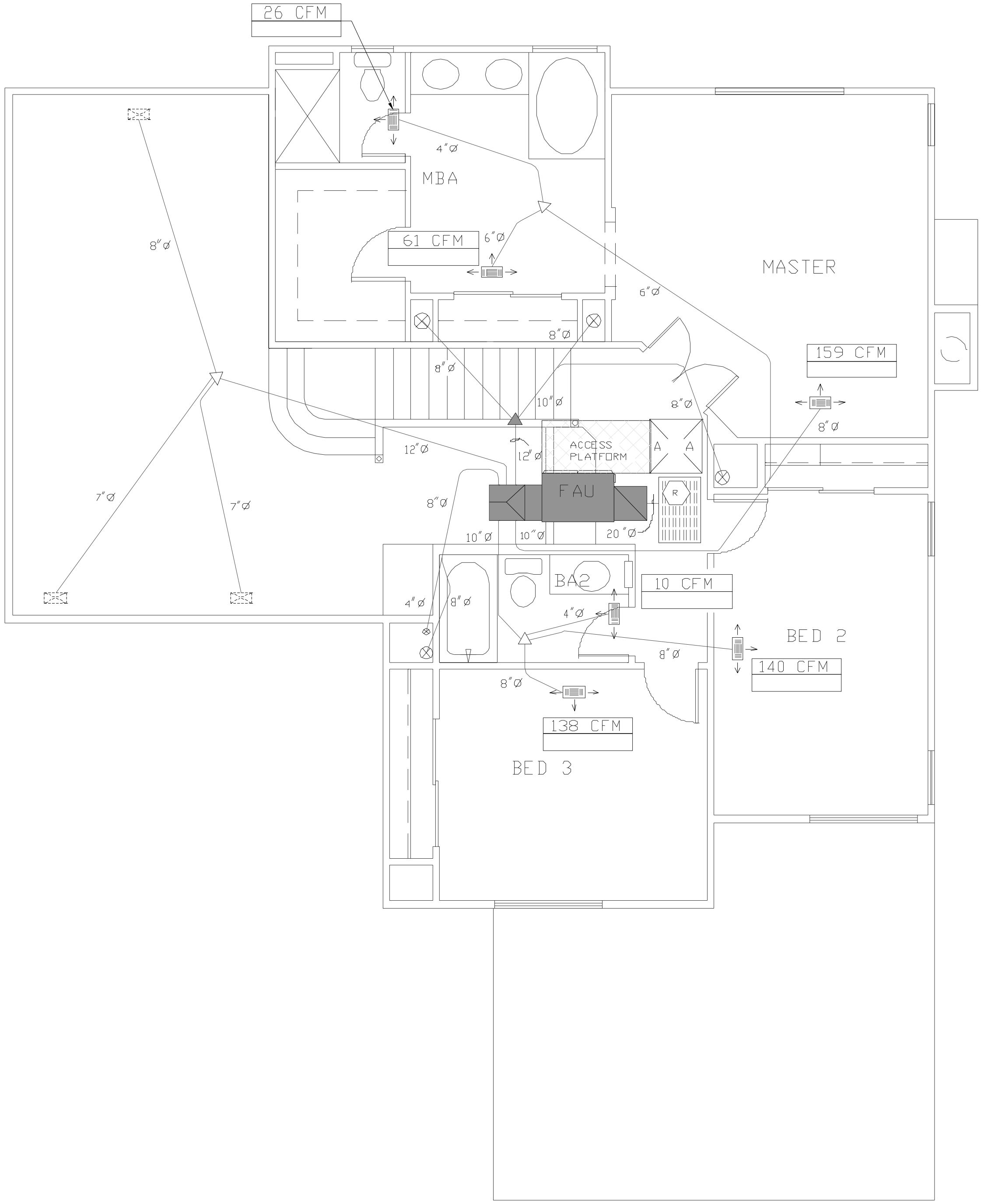

Figure 5 - Design 4, 2nd Floor HVAC Design

Design #5 – Two Story

Mayfair/Oak Glen II - 3148 square feet, 6 bedrooms, 3 baths.

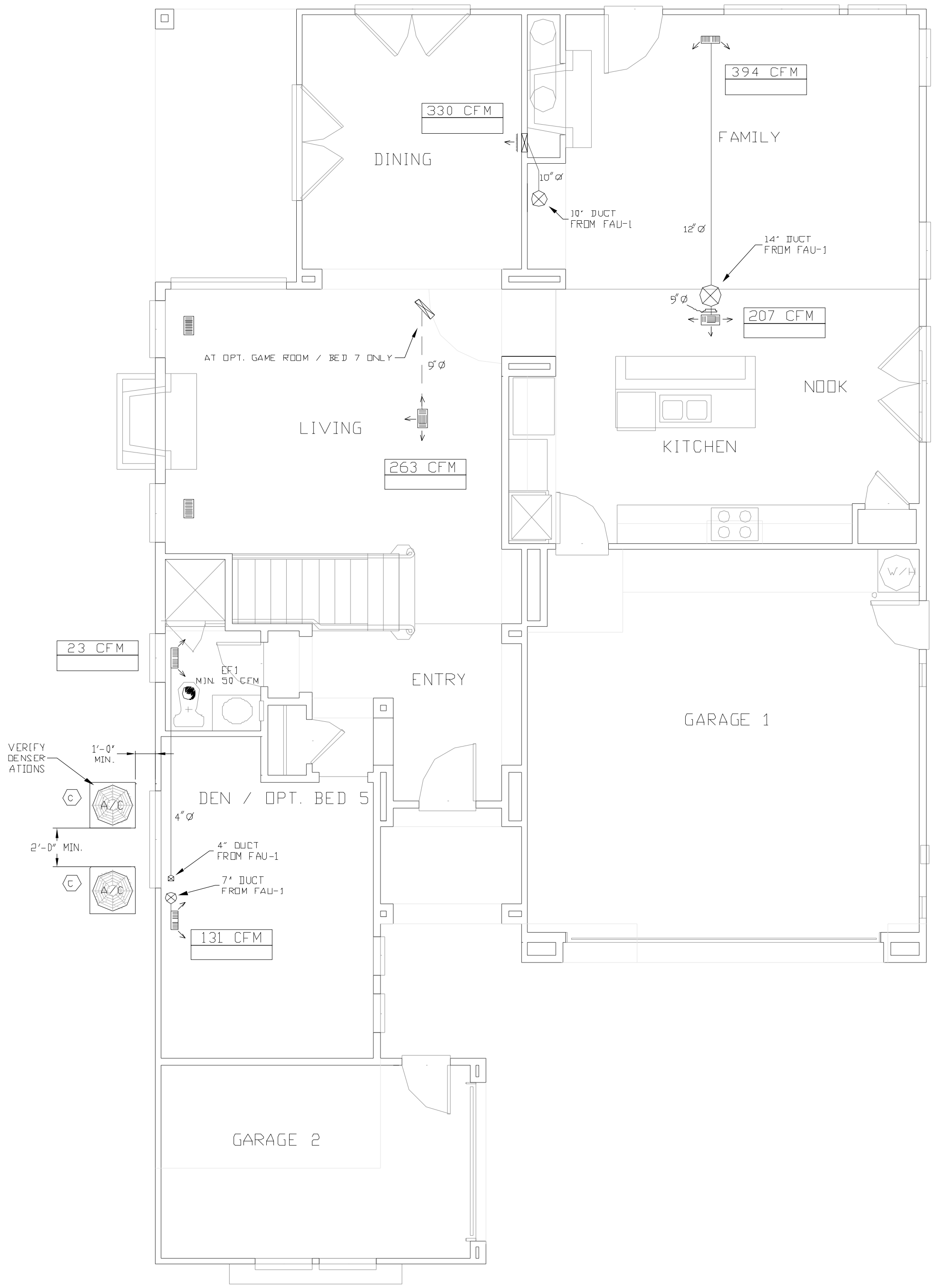

Figure 6 - Design 5, 1st Floor HVAC Design

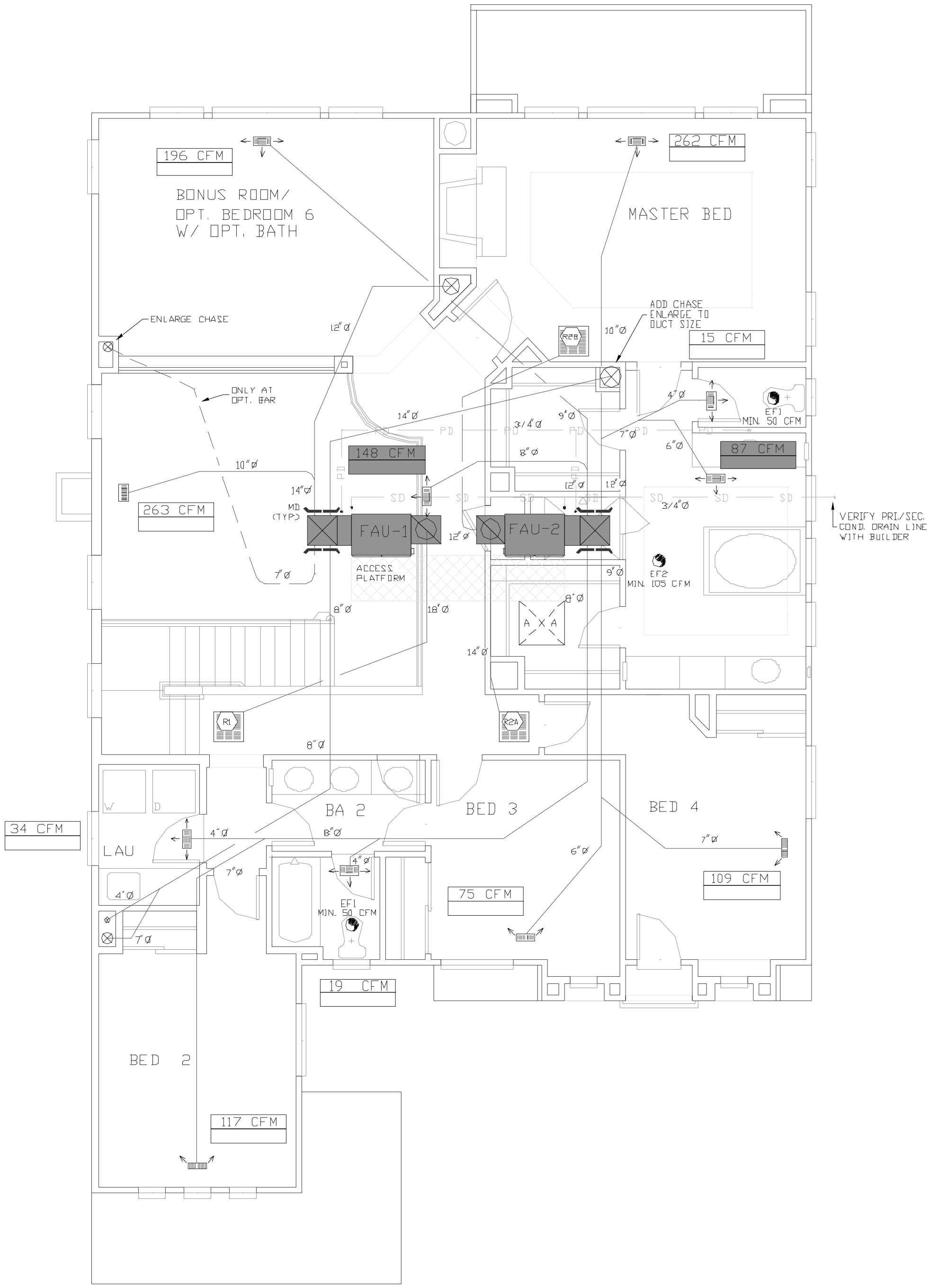

Figure 7 - Design 5, 2nd Floor HVAC Design

Design #6 – Two Story

Windmere Village 10, Plan 4A - 3194 square feet, 5 bedrooms, 3½ baths.

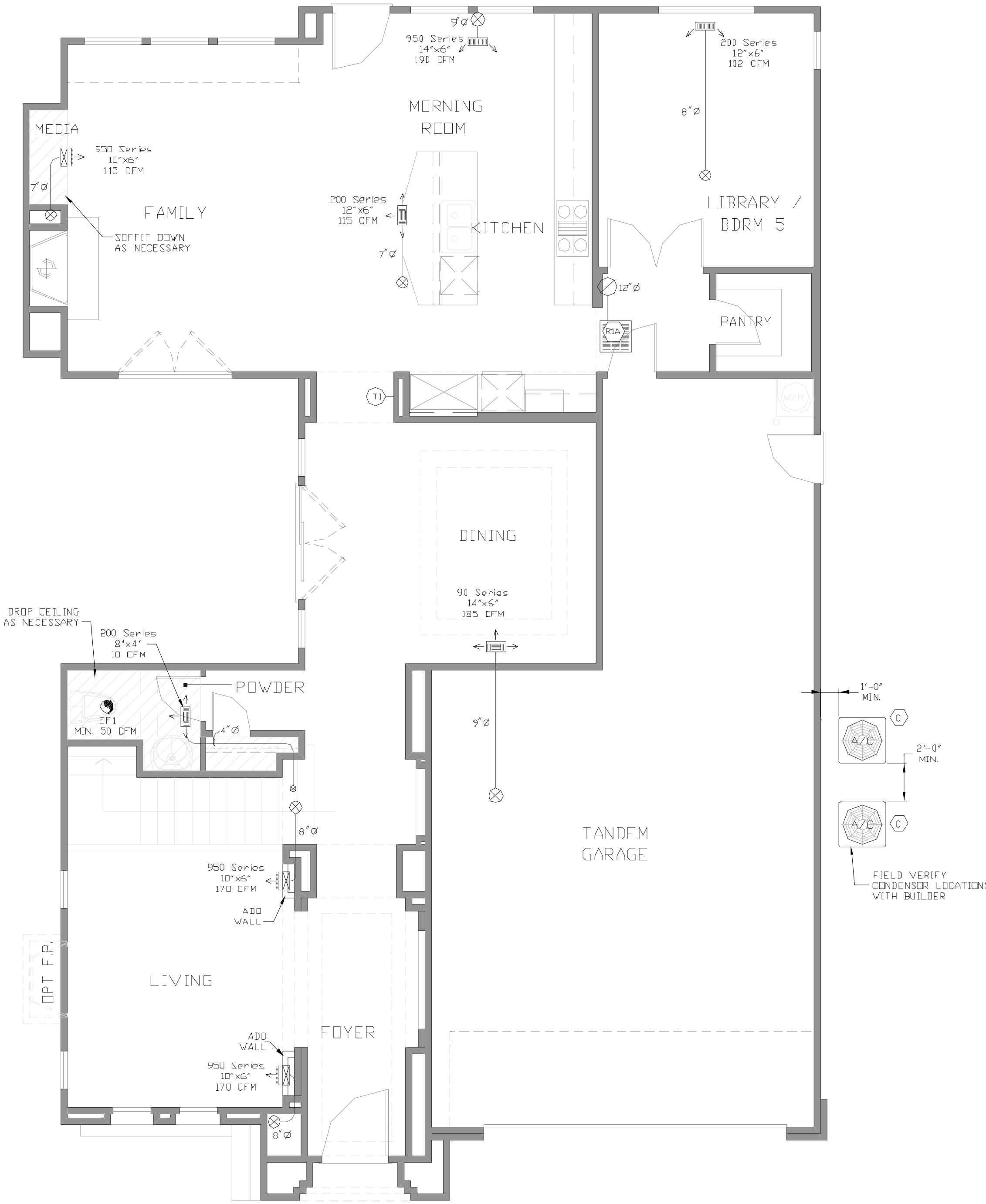

Figure 8 - Design 6, 1st Floor HVAC Design

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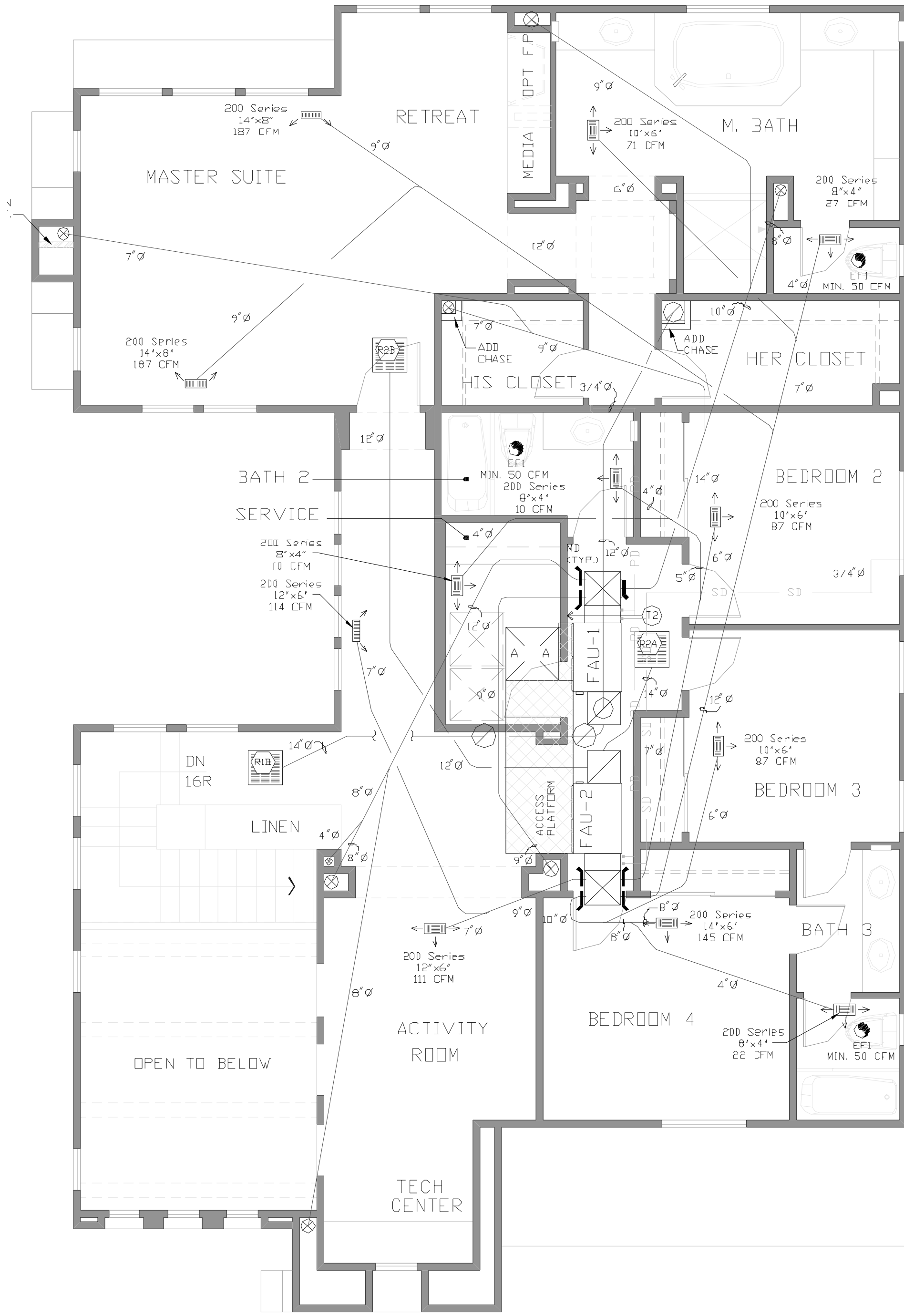

Figure 9 - Design 6, 2nd Floor HVAC Design

Design #7 – Townhome

Georgetown Townhomes, Unit B - 1584 square feet, 3 story, 3 bedrooms, 3 baths.

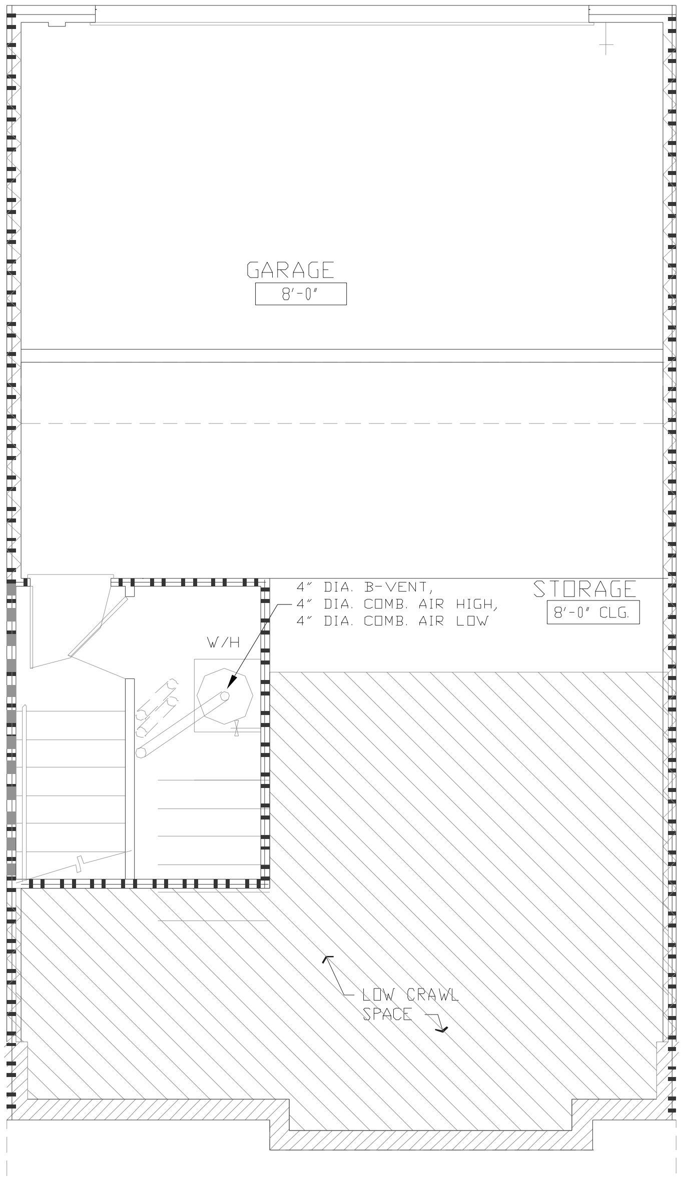

Figure 10 - Design 7, Basement HVAC Design

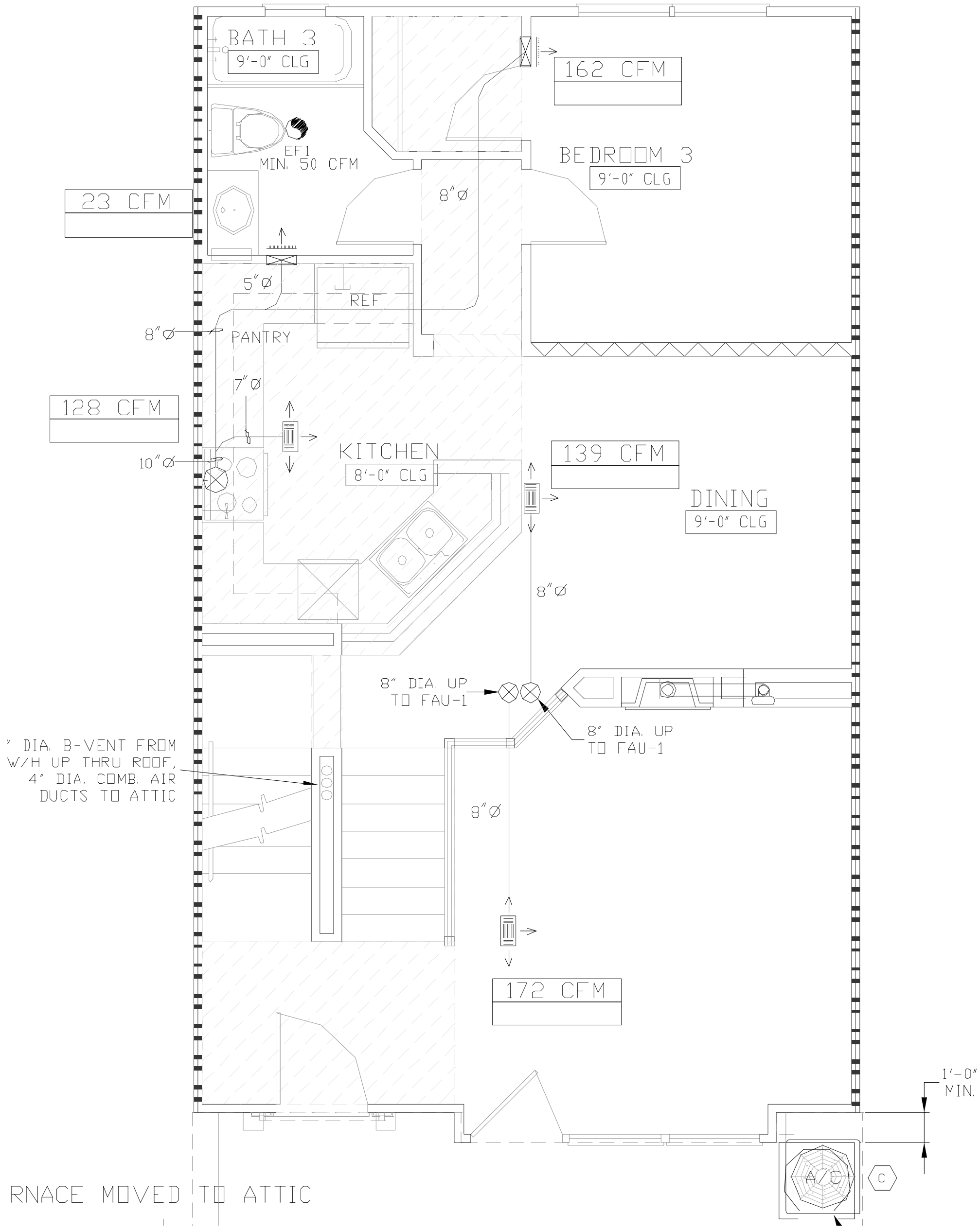

Figure 11 - Design 7, 1st Floor HVAC Design

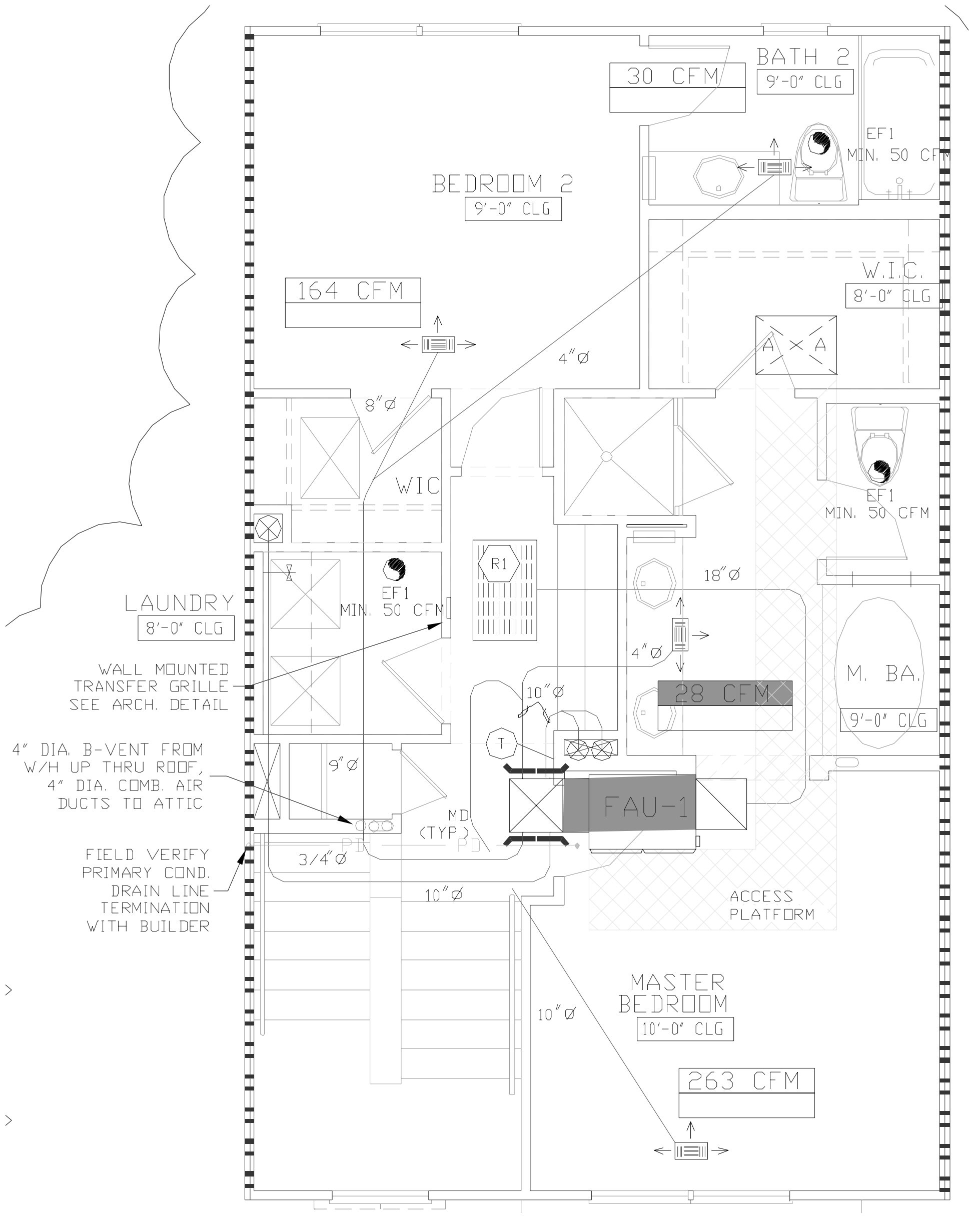

Figure 12 - Design 7, 2nd Floor HVAC Design

Design #8 – Townhome

Sansovino, Unit 2 - 1216 square feet, 2 story, 2 bedrooms, 2 baths.

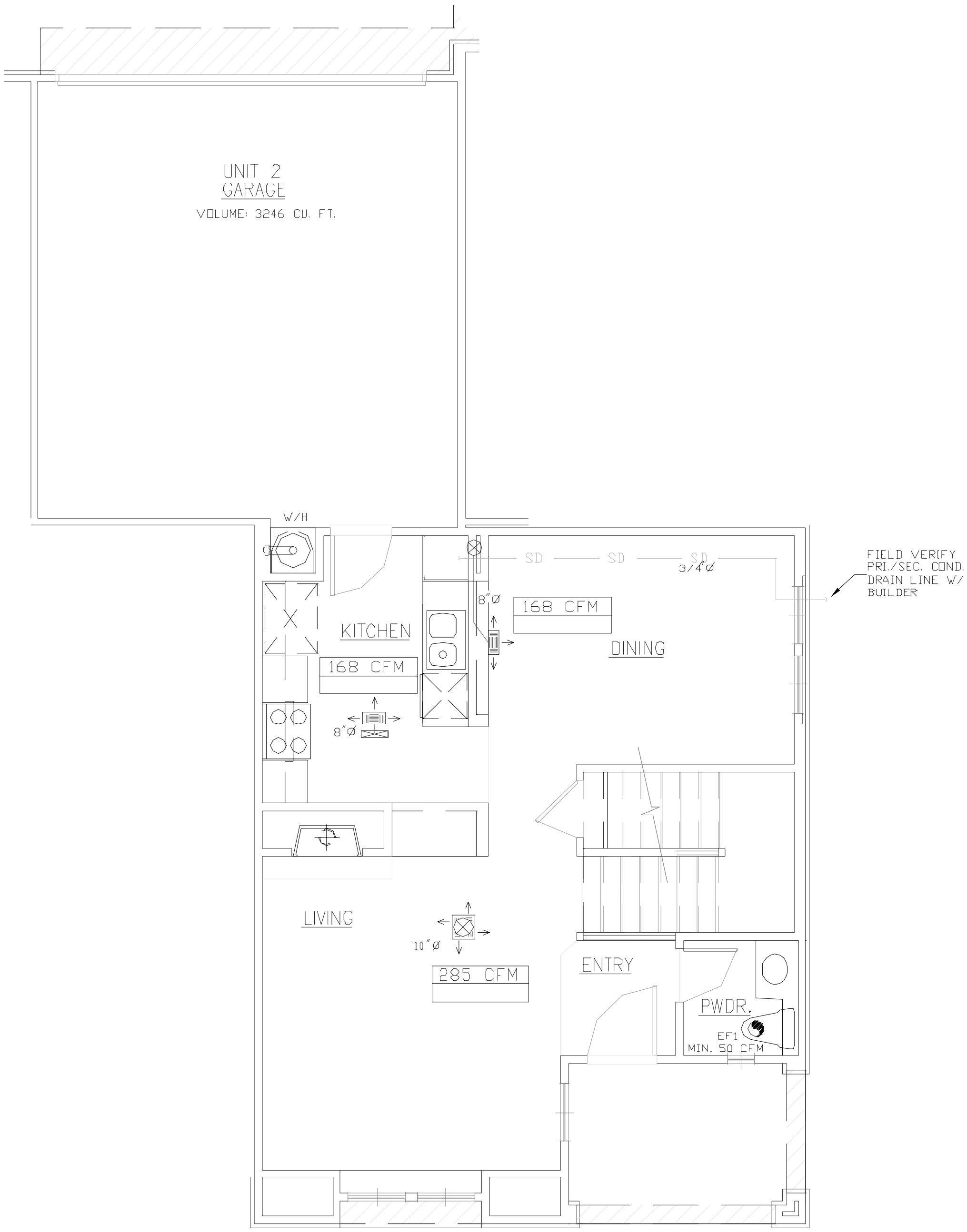

Figure 13 - Design 8, 1st Floor HVAC Design

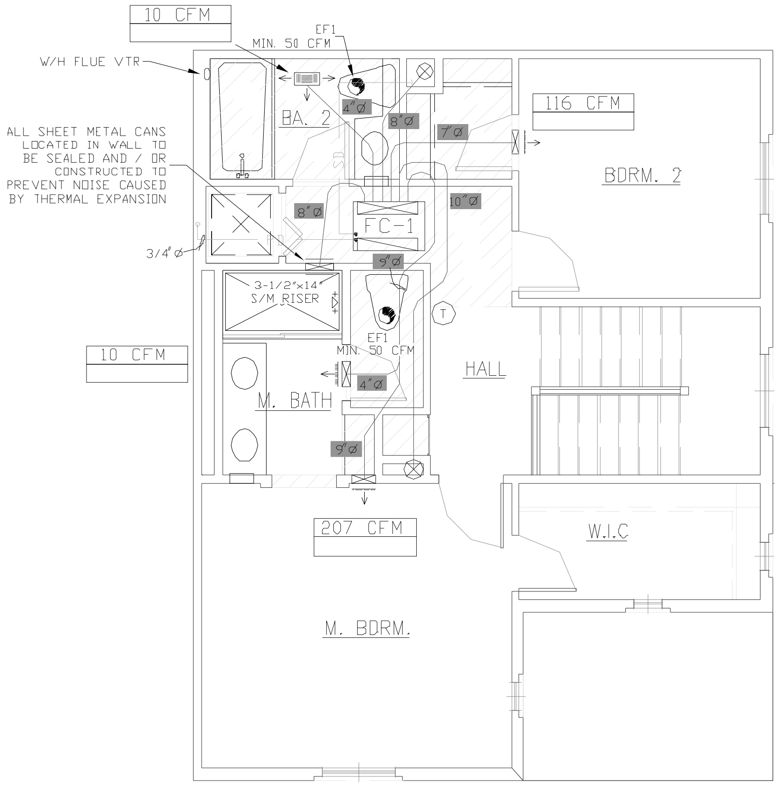

Figure 14 - Design 8, 2nd Floor HVAC Design

Design #9 – Townhome

Avendale P-3, Plan 2 - 1570 square feet, 2 story, 3 bedrooms, 2½ baths.

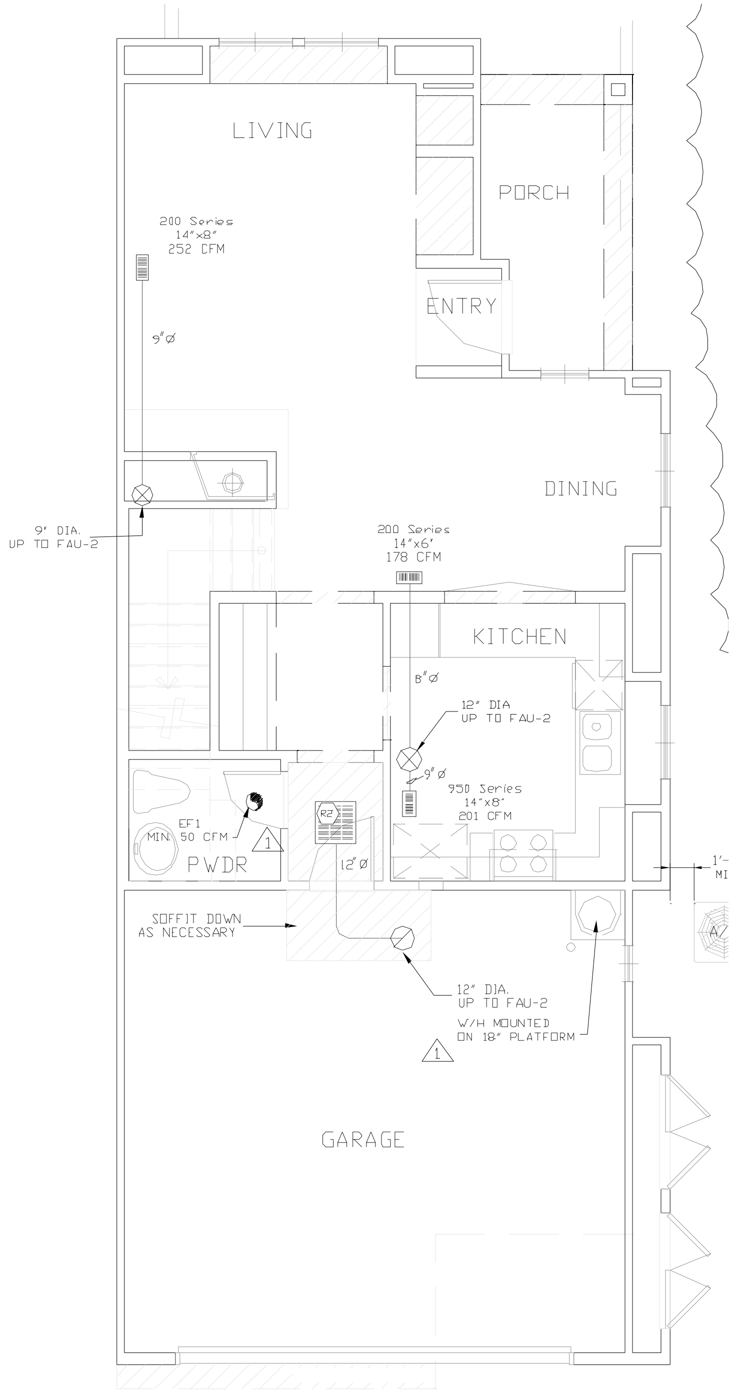

Figure 15 - Design 9, 1st Floor HVAC Design

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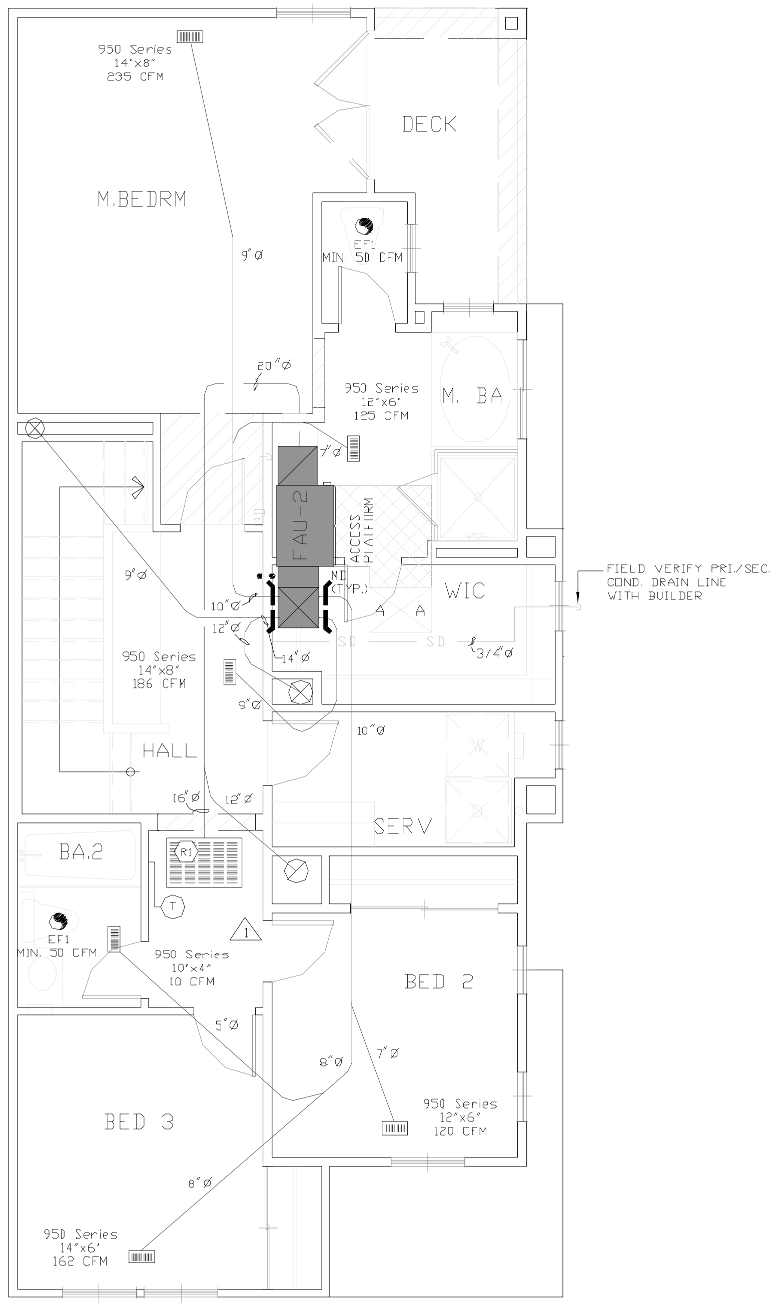

Figure 16 - Design 9, 2nd Floor HVAC Design

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